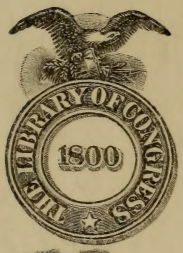

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A TREATISE

ON

ROADS AND PAVEMENTS

BY

IRA OSBORN BAKER, C.E., D. Eng'g

Professor of Civil Engineering, University of Illinois; Author of Masonry Construction, Engineer's Surveying Instruments; Member of American Society of Civil Engineers, Western Society of Engineers, Society for Promotion of Engineering Education

THIRD EDITION

RE-WRITTEN AND ENLARGED

FIRST IMPRESSION

NEW YORK

JOHN WILEY & SONS, Inc.

London: CHAPMAN & HALL, Limited

1918

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1918

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PREFACE

FIRST EDITION

THE object of this book is to give a discussion from the point of view of an engineer of the principles involved in the construction of country roads and of city pavements. The attempt has been made to show that the science of road making and maintenance is based upon well-established elementary principles, and that the art depends upon correct reasoning from the principles rather than in attempting to follow rules or methods of construction. In some cases practical experience has not yet determined the best method of procedure, and in these cases the conflicting views with the reasons for each are fully stated.

Considerable space has been given to the economics and location of country roads and to the construction and maintenance of earth roads, since such roads constitute more than ninety-five per cent of the mileage of the public highways and are greatly in need of careful consideration. It is frequently claimed by engineers that the public would be benefited by placing the care of the roads in the hands of engineers; but there is no evidence that any considerable number of engineers comprehend either the principles of road making necessary for the improvement and maintenance of our country roads, or the economic limitations and political difficulties of the problem. The first five chapters of this book are offered as a contribution to this phase of the good-road problem.

The remainder of the book, the portion that considers roads having permanently hard surfaces, which may not unfittingly be said to relate to urban and suburban roads, is based chiefly upon American experience, because the principles of road making worked out in this country are probably best suited to American conditions, and also because in most particulars American roads and pavements are superior to any other in the world. Some countries have more hard roads than this, because of a difference in conditions; but in no country does the quality of such roads average

better than in this. In some foreign cities the pavements seem to be better cared for than in this country, owing chiefly to different controlling conditions; but the principles of construction employed here are equal to the best. Notwithstanding the general excellence of the best American practice in constructing hard roads and pavements, there is still room for improvement in adapting the particular form of construction to the local conditions and also in preserving the surface from ruthless destruction. These two phases of the subject have been emphasized in the proper places in this volume. Throughout the attempt has been to state fully and clearly the fundamental principles of the construction and maintenance of roads and pavements.

In the preparation of the book the endeavor has been to observe a logical order and a due proportion between the different parts; and great care has been taken in classifying and arranging the matter. It will be helpful to the reader to notice that the volume is divided successively into parts, chapters, articles, sections having small-capital black-face side-heads, sections having lower-case black-face side-heads, sections having lower-case italic side-heads, and sections having simply the serial number. In some cases the major subdivisions of the sections are indicated by small numerals. The constant aim has been to present the subject clearly and concisely.

Every precaution has been taken to present the work in a form for convenient practical use and ready reference. Numerous cross references are given by section number; and whenever a table or a figure is mentioned, the citation is accompanied by the number of the page on which it may be found. The table of contents shows the general scope of the book; the running title assists in finding the different parts; and a very full analytical index makes everything in the book easy of access.

The author will esteem it a favor if any errors that may be found are at once brought to his notice.

I. O. B.

Champaign, Ill.,
November 27, 1902.

PREFACE

THIRD EDITION

THE numerous changes in methods of road and pavement construction have made necessary a radical revision of this volume. Five years ago, before many of the changes had become well established, a second edition was issued containing a supplementary chapter which briefly treated some of the new forms of construction. The present edition has been thoroughly revised and entirely rewritten. Five chapters of minor importance have been dropped to make room for an equal number of new ones. The number of illustrations has been greatly increased. No pains have been spared to bring the book up to date and to fully present the best modern practice.

Attention has been given to materials and forms of construction that affect the quality and cost of the road and pavement, rather than to the machines employed and the methods of doing the work. In other words, the book is intended more for the one who designs and inspects the road or pavement than for the contractor who constructs it. In recent years there have been developed a number of machines for doing road work and for handling road-building and paving materials that have greatly reduced the cost of road and pavement construction; but to have included an adequate discussion of such appliances and of modern methods of operation and organization would have greatly increased the size of the book.

Photographs from which illustrations have been made were obtained from the following:

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Portland Cement Association, Chicago, Ill.
Standard Oil Co., New York City, N. Y.
U. S. Office of Public Roads and Rural Engineering, Washington, D. C.
Mr. Walter Buehler, Chicago, Ill.
Mr. John S. Crandell, New York City, N. Y.
Mr. Harlan H. Edwards, Danville, Ill.
Mr. Richard H. Gillespie, Chief Engineer of Streets, Bronx, New York City.
Dr. Herman von Schrenk, St. Louis, Mo.

The following persons have generously given valuable suggestions on the subject stated.

Mr. Arthur N. Johnson, Chicago, Concrete Roads.
Mr. Walter Buehler, Chicago, Wood-block Pavements.
Mr. Philip P. Sharples, New York City, Bituminous Materials.
Mr. John W. Stipes, Champaign, Ill., many matters.
Mr. D. T. Pierce, Philadelphia, Sheet Asphalt Pavements.
Mr. W. C. Perkins, Conneaut, Ohio, Brick Pavements.
Mr. George N. Norton, Buffalo, N. Y., Cost of Maintenance of Sheet Asphalt Pavements.
Mr. Walter L. Weeden, Boston, Granite Block Pavements.

Valuable data were received from many, which are specifically acknowledged in the text.

To all of these the author gratefully acknowledges his obligations.

I. O. B.

Urbana, Illinois,
January 8, 1918.

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ROADS AND PAVEMENTS

INTRODUCTION

The problems involved in the construction and maintenance of rural highways differ materially from those which are encountered in the improvement and care of city streets, and therefore this discussion of the subject of Roads and Pavements will be divided into Part I, Country Roads, and Part II, City Pavements. In each division of the subject certain general principles will first be considered, and the further discussion will be divided according to the several materials in use for road surfaces. It will not always be possible to keep the several portions entirely distinct, but a knowledge of the intention in this respect will make it easier to understand the method of presentation or to turn readily to the discussion of any particular phase of the subject.

The classification of road surfaces into country Roads and City Pavements is partly according to the most general use of each, and partly according to the elaborateness of the construction. According to the somewhat loose classification here adopted road surfaces for country roads consist of two parts, subgrade and wearing coat; while city pavements consist of four parts, subgrade, foundation, a binder or cushion course, and a wearing coat.

PART I

COUNTRY ROADS

PART I will include matters relating to earth, sand and sand-clay, gravel, water-bound macadam, bituminous macadam, and concrete roads in rural districts, although some of the discussion is also applicable to these road surfaces when employed in city streets.

CHAPTER I

ROAD ECONOMICS AND ROAD ADMINISTRATION

ART. 1. ROAD ECONOMICS

1. ADVANTAGES OF GOOD ROADS. Good roads are so important to the financial, social and educational well-being of a rural community that no enumeration of their advantages is likely to include all the benefits; but a brief consideration of some of the chief advantages of good roads will be of value in determining the amount of money that may justifiably be expended to secure road improvement and in deciding who should in equity bear this expense. The principal advantages of good roads, i. e., of permanently hard ones, are as follows:

1. Good roads decrease the cost of transportation,—at some seasons of the year considerably, but at others very little. This item will be considered more fully later (see § 4–9).

2. Good roads make the marketing of crops easier. This advantage results in extending the area devoted to the cultivation of fruits and vegetables, and is most effective in the vicinity of a large city.

3. Good roads give a wider choice of time for the marketing of crops. In some instances good roads permit the marketing of crops when the labor of production is not pressing; but this advantage

accrues only to the producers of imperishable crops, and is not of great importance since the labor required to market the product is small in comparison with that of production.

4. Good roads permit the marketing to be done when prices are most favorable. This advantage is more important with perishable than with imperishable products. As far as perishable products are concerned, this advantage is virtually included in paragraph 2 above. As far as imperishable products are concerned, this advantage is important only near a large city, i. e., where the producer hauls to the market. Prices of staple farm products (not garden products) are not much affected by roads, since the condition of the roads is local while prices are governed by world-wide conditions. Writers on good-road economics usually greatly overestimate this advantage as far as the ordinary producer of imperishable products is concerned. If this advantage were anything like as great as is frequently claimed, producers would store such products at the local shipping point, or in the great city, or at the port of export, awaiting a favorable price. Such storage would also permit the delivery at a time when other work was least pressing. The expense of storage at the local shipping point is a small per cent of the value of the product. It is frequently, but erroneously, claimed that hard roads would save the Illinois farmer 3 to 5 cents per bushel—an amount 10 to 15 times the cost of storage. Since producers do not so store their products, it is safe to assume that this advantage of good roads as a rule, is not very great. The present method of doing business makes this advantage comparatively unimportant.

5. Good roads give a wider choice of the market place. This advantage affects perishable products chiefly, and for geographical reasons is, as a rule, not very great.

6. Good roads tend to equalize the produce market between different weather conditions. In the absence of railroad transportation and cold storage, this advantage might be of considerable local importance; but under ordinary conditions it is comparatively unimportant.

7. Good roads tend to equalize railroad traffic between the different seasons of the year. Impassable wagon roads over any considerable area materially decrease the amount of agricultural products to be transported by railroads, and a return of good roads will for a time congest the railroad transportation facilities. The effect of good roads in equalizing railroad transportation is partially

neutralized by the fact that agricultural products are only one of many classes of commodities transported by the railroads; and also by the fact that most railroads transport agricultural products originating over a considerable area, and bad wagon roads are not likely to occur over all the contributory area at the same time; and further by the fact that the storage capacity of warehouses helps to equalize the traffic.

8. Good roads tend to equalize mercantile business between different seasons of the year. Merchants having a considerable rural custom could do business more economically if the trade were distributed uniformly throughout the year. However, the succession of good and bad wagon roads is only one cause of the unequal distribution of rural patronage.

9. Good roads permit more easy intercourse between the members of rural communities, and also between rural and urban populations. This is an important benefit, particularly under a democratic form of government.

10. Good roads facilitate the consolidation of rural schools, and thereby increase their economy and efficiency. This is an important matter to coming generations.

11. Good roads facilitate rural mail delivery, and thereby tend to improve the social and intellectual condition of the rural population.

12. Good roads sometimes change rural into suburban property.

13. Good roads are a material factor in stimulating tourist travel and making rural communities attractive to vacation residents.

2. It is customary to include the increase in the price of farming land as one of the benefits of good roads; but the increase in price of land is simply the measure of the value of all the above advantages, and hence should not be included.

3. Notice that the first eight advantages mentioned above relate to the financial benefits of good roads, and the last four to the social benefits. In the past writers upon good-road economics have given much attention to the supposed financial benefit of hard roads and little or none to the social advantage. Any considerable expenditure for the improvement of rural highways can not be justified on financial grounds alone (§ 12). Good roads are desirable for the same reason that a man buys an automobile or builds a fine house, i. e., because they are a comfort and a pleasure. Good roads should be urged principally for the same reason that good schools are maintained, namely, because they increase the intelligence and value of the citizen to society.

4. Cost of Wagon Transportation. The chief financial advantage of hard roads is the decreased cost of transportation. It is proposed to inquire briefly concerning the cost of wagon transportation with a view of determining the proportion of this cost that may be saved by road improvement.

In this connection, a distinction must be made between the cost to those whose chief business is to sell transportation, and the cost to those to whom transportation is a mere incident of a business organized for some other purpose. The first class is represented by a freighter, and the second by a farmer. The former maintains his teams and wagons only to transport freight, while the latter ordinarily keeps his teams and wagons primarily for general farm work of which transportation on the roads is only a small part. In some cases the traffic to be considered is principally that by freighters, but usually the chief traffic over country roads is that connected with agricultural operations.

Again, consideration should be given only to hauling in which the load is equal to the full capacity of the team for the particular condition of the roads. A farmer may employ a two-horse team to take a bushel of potatoes to town, or a grocery wagon may make a trip to deliver a pound of cheese; but the partial load is entirely independent of the condition of the roads.

Further, it is necessary to notice that only the rate for full loads should be considered. If a number of packages are carried in the same load for different parties, part of the charge is to cover the cost of collection, distribution, possible partial loads, etc.; and therefore only part of the charge is for transportation proper.

5. Cost to Freighters. The cost will vary greatly with the conditions of the service, i. e., with the character of the road surface, the average grade of the road, the maximum grade, return load, etc.

Except in rare cases, the cost per ton-mile for loads one way upon earth roads will not be more than 25 cents, and ordinarily it will not be more than 15 to 20 cents;* while with easy grades and favorable road surface it may be as low as 10 to 15 cents, and with long hauls, return loads, and favorable road surface, it may be 8 to 10 cents. When the last price is obtained there is little need or opportunity for road improvement.

6. Cost to Farmers. In this division of the subject, a distinction should be made between producers of perishable products and

* See "Cost of Wagon Transportation," by the author, in Proceedings of Illinois Society of Engineers, Vol. 16 (1901), p. 36–44; full abstract of the same in *Engineering News*, Vol. 45 (1901), p. 86.

producers of non-perishable products. The first class is represented by gardeners, dairymen, fruit-growers, etc.; and the second, by producers of hay, grain, cotton, etc.

The cost of transportation is much greater for perishable than for non-perishable products. In the first place, the marketing of perishable products is an important factor in comparison with the cost of production, and frequently necessitates an independent transportation department; while the labor of marketing non-perishable products is comparatively small—particularly as in most localities where there is much of this class of produce, the distance from the farm to the railroad station is short. Further, perishable products must go to market whatever the condition of the roads, while non-perishable ones can wait for comparatively favorable conditions; and finally, the former frequently go to market in partial loads, and the second usually in full loads. Except in comparatively limited districts, non-perishable products make up the bulk of the traffic on the country roads. According to the U. S. Census of 1890, the gardeners, fruit-growers, dairymen, vine-growers, florists, and nurserymen constitute only 1.8 per cent of the so-called farming class.

7. The cost of transporting perishable products is probably greater than that for any other class of traffic over the country roads; but as it is next to impossible to secure any reliable data no attempt will be made to present any general conclusions. For several reasons, this traffic will usually justify larger expense for road improvement than any other.

The cost of transportation to farmers proper, i. e., producers of non-perishable products, depends chiefly upon the condition of the road surface and upon the demands of general farm work. Loam or clay roads are reasonably good when dry, and are therefore at least passable most of the year; while sand roads are at their worst when dry, and are therefore in their worst condition during the greater part of the year. Fortunately sand roads are less common, the country over, than clay or loam roads. In the crop season, with a little choice as to the time of doing the work the cost on fairly level loam or clay roads is probably not more than 10 to 12 cents per ton-mile; and when farm work is not pressing, the cost is not more than 8 to 10 cents per ton-mile.*

* See "Cost of Wagon Transportation," by the author, in Proceedings of Illinois Society of Engineers, Vol. 16 (1901), p. 36–44; full abstract of the same in *Engineering News*, Vol. 45 (1901), p. 86.

8. A Conflicting View. In current literature on road economics, the claim is frequently made that the cost of wagon transportation to the farmer is considerably more than stated in § 7. Apparently most of these claims are based, either directly or indirectly, upon data published in Circular 19 of the Road Inquiry Office of the United States Department of Agriculture under date of April 4, 1896. Table 1 is a brief summary from that circular.

The conclusions of this circular have been so widely quoted and so generally accepted as to justify a brief consideration. In former editions of this book these conclusions were somewhat carefully considered, and the following is a brief summary of that investigation.

TABLE 1

ALLEGED COST OF WAGON TRANSPORTATION

Ref. No.	Locality.	Average Distance Hauled, Miles.	Average Load Hauled, Tons.	Average Cost per Ton-mile, Cents.	Total Cost from Farm to Market, per Ton.
1	Eastern States	5.9	1.108	32	$1.89
2	Northern States	6.9	.....	27	1.86
3	Middle-Southern States	8.8	.....	31	2.72
4	Cotton States	12.6	0.688	25	3.05
5	Prairie States	8.8	1.204	22	1.94
6	Pacific Coast and Mountain	23.3	1.098	22	5.12
7	Whole United States	12.1	1.001	25	3.02

Circular 19 concludes that 313,349,227 tons were hauled over the highways of the United States in 1895 at a cost of $3.02 per ton-mile, or a total cost of $946,314,665.54; and that the annual cost of transporting the crops of the United States to market was 26.6 per cent of the price of the crops at the market. These conclusions are greatly in error chiefly for the following reasons:

1. The investigation was not very elaborate, since replies were received from only one county in thirty.

2. The average distance hauled seems to be about twice too great.

3. The value for the average load hauled is approximately twice too great. The mean between the maximum and the minimum load may be one ton; but the great bulk of teaming is done when the roads are at least in fair condition, when the load is con-

siderably more than one ton. The author has examined the records of several grain buyers in central Illinois, where at times the roads are as bad as anywhere, and finds that the average load is nearly a ton and a half. Statistics for marketing over 300,000 bushels of corn in Illinois gives the average load as almost exactly 2 tons.

4. The cost per ton-mile indicates that this value was obtained by assuming that the wages of wagon, team, and driver are 35 cents per hour; that the team travels 3 miles per hour; and that the team hauls a load only one way. The price per hour for a team is too great, since the cost per day as reported by 316 farmers in 76 counties in Illinois varied during crop time from $1.40 to $2.74, the average being only $2.13, or say 21 cents per hour.

5. No account was taken of the relative amounts of traffic in the several states.

9. Under date of Feb. 28, 1907, the Bureau of Statistics of the U. S. Department of Agriculture published Bulletin 49—Cost of Hauling Crops from Farm to Shipping Point. In the latter investigation the cost of hauling the twelve leading farm products from the farm to the shipping point during the crop year of 1905–06 is said to be $84,684,000; whereas in the first investigation (§ 8), the cost in 1895 of hauling all crops from the farm to the market was said to be $652,000,000. Notice that the cost according to the later and more elaborate investigation is only about one eighth of that by the former investigation, notwithstanding the fact that the weight of the seven leading crops was almost exactly 50 per cent greater in 1905 than in 1895; in other words, on the face of the returns, the result in the first bulletin is about sixteen times too great.

Further, the result of the second investigation is subject to errors 2, 3, and 4 of § 8. Besides, the second bulletin is greatly in error for the following reasons: It finds the cost of hauling crops from the farm to the market to be $72,984,000; and then adds $11,700,000 as the cost of hauling wheat to local mills to be ground. This allowance is altogether too great, since it assumes that more than one third of the wheat not used for seed is ground at the local mill; while only an inappreciable quantity is so used.

Correcting the above errors would reduce the total of the second bulletin to one half or one third, and make the result in the first bulletin thirty to fifty times too great. Unfortunately the results of the first investigation are frequently used in discussions on road

economics, and the object of this note is to show their utter unreliability.*

10. Possible Annual Saving. The Office of Road Inquiry, in Circular No. 19, to which reference has been made, estimates the possible annual saving by road improvement as $628,000,000. This estimate is based upon a comparison of the data in Circular No. 19 with that on the "Cost of Hauling Farm Products to Market or Shipping Point in European Countries, Collected by U. S. Consular Agents," published in Circular No. 27 (Feb. 5, 1897) of the Office of Road Inquiry of the U. S. Department of Agriculture. The average cost as given in the latter circular is 10 cents per ton-mile, and the difference between this and the average stated in Table 1 is 15 cents per ton-mile, which is two thirds of the average value in Table 1.

Concerning the data for America, notice that they are taken from Circular No. 19, and are greatly in error as has already been shown. Concerning the data for Europe, notice in the first place that they are open to most of the criticisms made against the data in Table 1. In the second place, the twelve results given in Circular 27 vary from 4 to 30 cents per ton-mile, which is too wide a range and too few results for an accurate determination of the average cost of wagon transportation in Europe. In the third place, some of the results are professedly the cost to transportation companies, and some the cost to farmers to whom the hauling of the crops to market is merely an incident of farm work. And, finally, the data for the cost of hauling not done by transportation companies are for hauling garden products, etc., to large cities, and are therefore not representative of the cost of transporting general farm products to market.

11. It is very unfortunate that the conclusions from the two Circulars referred to above, have been so generally accepted by speakers and writers upon good-road economics. Country roads are used chiefly by farmers, and if improvements are made they must be paid for largely, if not entirely, by farmers; and therefore the cooperation of farmers must be secured before any improvement of the country roads is possible. Farmers know that conclusions such as are deduced above from Table 1 are ridiculous; and not unnaturally distrust the motives prompting the argument,

* For a further discussion of the Circular see the following: In defense of the Circular, *Engineering News*, Vol. 34, p. 410–11; do., Vol. 45, p. 50–51. Controverting the Circular: *Engineering News*, Vol. 34, p. 377–78; do., Vol. 34, p. 410–11; do., Vol. 44, p. 337–44; do., Vol 5, p. 48–49; do., Vol. 57, p. 428.

and are hostile to all propositions for road improvement supported by such arguments.

Further, it is not possible to determine either the cost of wagon transportation or the financial value of road improvement in the wholesale manner proposed in the above Circulars. The cost of haul and the value of improved roads vary greatly with local conditions; and consequently a special investigation should be made for each particular case.

However, it should be borne in mind in discussing road economics that financial profit is only one of the advantages of good roads (see § 1–3).

12. Financial Value of Road Improvement. It is not possible to present any valuable general conclusions as to the saving in cost of transportation attainable by any proposed road improvement.

For any particular road where the traffic is principally by "freighters" as defined in § 5, it is possible to arrive at a rough approximation by (1) taking a census of the traffic, (2) making an estimate of the present cost per ton-mile, and (3) making an estimate of the cost after the improvement. The amount of traffic varies with the condition of the road surface, and the chief difficulty is to determine the advantage of being able to move freight at any time. This advantage will depend upon the proportion of the time that the roads are "good," which depends entirely upon the locality and the nature of the road surface, and varies greatly from year to year. Ordinarily the road is used by a variety of teamsters, and the cost varies with the particular circumstances of each. There will rarely be conditions to which this method of investigation can be applied with any degree of certainty. At best the results of such an investigation must be regarded as mere approximations, since no factor of the problem can be determined accurately, and since any slight error in the estimated saving per ton-mile is greatly magnified when multiplied by the number of ton-miles. Nevertheless such an investigation is desirable to aid the judgment, but its approximate nature must not be forgotten.

For roads where the travel is by farmers the difficulties are still greater. The number of users is greater, the cost of transportation to the different users varies very greatly, and the value of being able to use the road at any time is very different with different users, and for the same class of users varies with the locality and the nature of the road.

The amount of money that may justifiably be expended for any proposed road improvement will depend upon the present condition of the road, the amount and the nature of the travel, and the cost of constructing and maintaining the improved road. The question is a local one, and can be answered approximately correctly only after careful study of the conditions. Ordinarily the saving in transportation, except near large cities, will not justify any radical road improvement; but with a miscellaneous travel, the social advantages of road improvement should be taken into consideration, even though they can not be computed in dollars and cents.

13. TRACTIVE RESISTANCE. The solution of some problems connected with road improvement requires a knowledge of the tractive resistance. Until recently all vehicles were horse-drawn; but now many are propelled by motors. The passenger automobile with its wide range of speed and power is able to surmount almost any grade likely to be encountered upon a road used also by horse-drawn vehicles; and automobile trucks are not common, at least yet, upon rural roads, and besides the factors governing the tractive power of such vehicles are not yet well established. Hence the road problems involving tractive resistance relate almost exclusively to horse-drawn vehicles; and consequently only this class will be considered under this head.

The resistance to traction of a vehicle on a road consists of three independent elements: axle friction, rolling resistance, and grade resistance.

14. Axle Friction. The resistance of the hub to turning on the axle is the same as that of a journal revolving in its bearing, and has nothing to do with the condition of the road surface. The coefficient of journal friction varies with the material of the journal and its bearing, and with the lubricant. It is nearly independent of the velocity, and according to observations made by the author seems to vary about inversely as the square root of the pressure. For light carriages when loaded, the coefficient of friction is about 0.020 of the weight of the axle; for heavier carriages when loaded, it is about 0.015; and for the ordinary thimble-skein American wagon when loaded, it is about 0.012. The above results are for good lubrication; if the lubrication is deficient, the axle friction is two to six times as much as above. The above figures agree reasonably well with results obtained for journal friction of machines. Apparently the value of this coefficient in Morin's experi-

ments (§ 20) was 0.065.* The greater axle friction is probably due to the inferior mechanical construction of French carriages and wagons of that date.

The tractive power required to overcome the above axle friction for American carriages of the usual proportions is about 3 to $3\frac{1}{2}$ lb. per ton of the weight on the axle; and for truck wagons, which have medium-sized wheels and axles, is about $3\frac{1}{2}$ to $4\frac{1}{2}$ lb. per ton.

15. Rolling Resistance. The resistance of a wheel to rolling along on a road is due to the yielding or indentation of the road, which causes the wheel to be continually climbing an inclination. The resistance is measured by the horizontal force necessary at the axle to lift the wheel over the obstacle or to roll it up the inclined surface; and varies with the diameter of the wheel, the width of the tire, the speed, the presence or absence of springs on the vehicle, and the nature of the road surface.

16. *Diameter of Wheel.* The rolling resistance varies inversely as some function of the diameter of the wheel, since the larger the wheel the less the force required to lift it over the obstruction or to roll it up the inclination due to the indentation of the surface. Table 2 shows the results obtained by Mr. T. I. Mairs at the Missouri Agricultural Experiment Station,* with three different-sized

TABLE 2

EFFECT OF SIZE OF WHEELS ON TRACTIVE RESISTANCE †

Resistances in Pounds per Ton

Ref. No.	Description of Road Surface.	MEAN DIAMETER OF FRONT AND REAR WHEELS.		
		50″	38″	26″
1	Macadam: slightly worn, clean, fair condition....	57	61	70
2	Gravel road: dry, sand 1″ deep, some loose stones.	84	90	110
3	Gravel road: up grade 2.2%, ½″ wet sand, frozen below.....	123	132	173
4	Earth road: dry and hard.....	69	75	79
5	" " ½″ sticky mud, frozen below, rough..	101	119	139
6	Timothy and blue-grass sod: dry, grass cut.....	132	145	179
7	" " " " wet and spongy.....	173	203	281
8	Corn-field: flat culture, across rows, dry on top...	178	201	265
9	Plowed ground: not harrowed, dry and cloddy ...	252	303	374
10	Average value of the tractive power.....	130	148	186

* Lowe's Strassebaukunde, page 75. Wiesbaden, 1895.

† Missouri Agricultural Experiment Station, Bulletin No. 52, Columbia, 1902.

wheels. The 50-inch represents 44-inch front and 56-inch hind wheels; the 38-inch represents 36-inch front and 40-inch hind wheels; and the 26-inch represents 24-inch front and 28-inch hind wheels. The tires were 6 inches wide. The load was practically $1\frac{3}{4}$ tons in each case.

Morin concluded that the resistance varies inversely as the first power of the diameter of the wheel; Dupuit that it varies as the square root; and Clarke claims that it varies as the cube root.* According to some experiments made in England in 1874,† the tractive resistance varied more rapidly than the first power of the diameter of the wheels. The mean results in Table 3 vary nearly inversely as the square root of the mean diameter—certainly more nearly than as either the first power or the cube root. For obvious reasons, the experiments can not be very exact; and apparently the tractive resistance varies differently for different surfaces. The exact determination of the law of variation is of no great importance.

17. *Width of Tire.* If the wheel cuts into the road surface, the tractive resistance is thereby increased; but with surfaces for which there is little or no indentation, the traction is practically independent of the width of tire.

Table 3, page 15, shows the results of an elaborate series of experiments by the Missouri Agricultural Experiment Station.‡ The load in each case was 1 ton. These results show that on poor macadam, poor gravel, and compressible earth roads, and also on agricultural land, the broad tire gives less resistance except as follows: (1) when the earth road is sloppy, muddy, or sticky on top and firm underneath; (2) when the surface is covered with a very loose deep dust and is hard underneath; (3) when the mud is very deep and so sticky that it adheres to the wheel; or (4) when the road has been rutted with the narrow tire. The last conclusion was established by a large number of experiments not included in Table 3.

Table 4, page 16, gives data on the effect of width of tire upon the tractive power, obtained by the Studebaker Bros. Manufacturing Co., South Bend, Ind., in 1892, with an ordinary $3\frac{1}{2}$-inch thimble-skein wagon. Notice that on a hard and incompressible road surface, e. g., wood block pavement and gravel, the narrower tire draws

* Clarke's Construction of Roads and Streets, p. 294. London, 1890.

† Clarke's Manual of Rules, Tables and Data for Mechanical Engineers, p. 962. London, 1877.

‡ Missouri Agricultural Experiment Station, Bulletin No. 39, Columbia, Mo., July, 1897.

TABLE 3

Tractive Resistance of Broad and Narrow Tires *

Resistances in Pounds per Ton

Ref. No.	Description of the Road Surface.	Width of Tire.		No. of Trials.
		1½″.	6″.	
	Broken Stone Road:			
1	Hard, smooth, no dust, no loose stones, nearly level	121	98	2
	Gravel Road:			
2	Hard and smooth, few loose stones size of black walnuts	182	134	2
3	Hard, no ruts, large quantity of sand which prevented packing	239	157	1
4	New, gravel not compact, dry	330	260	1
5	Wet, loose sand 1″ to 2½″ deep	246	254	2
	Earth Roads:			
6	Loam,—dry, loose dust 2″ to 3″ deep	90	106	2
7	" " hard, no dust, no ruts, nearly level.	149	109	3
8	" stiff mud, drying on top, spongy below.	497	307	1
9	" mud 2½″ deep, very sticky, firm below.	251	325	1
10	Clay,—sloppy mud 3″ to 4″ deep, hard below.	286	406	1
11	" dry on top but spongy below, narrow tires cut in 6″ to 8″	472	422	2
12	" dry on top but spongy below	618	464	5
13	" stiff deep mud	825	551	1
	Mowing Land:			
14	Timothy sod,—dry, firm, smooth, narrow tire cuts in 1″	317	229	1
15	" " moist, narrow tire cuts in 3½″	421	305	1
16	" " soft and spongy, grass and stubble 3″ high, narrow tire cuts in 6″	569	327	1
	Pasture Land:			
17	Blue-grass sod,—dry, firm, smooth	218	156	2
18	" " soft, narrow tire cuts in 3″	420	273	2
19	" " narrow tire cuts in 4″	578	436	1
	Stubble Land:			
20	Corn stubble,—no weeds, nearly dry enough to plow	631	418	2
21	" " some weeds and stalks, dry enough to plow	423	362	1
22	" " in autumn, dry and firm	404	256	2
	Plowed Land:			
23	Freshly plowed, not harrowed, surface rough	510	283	1
24	" " harrowed, smooth, compact	466	323	1

* Missouri Agricultural Experiment Station, Bulletin No. 39, Columbia, Mo., July, 1897.

TABLE 4

EFFECT OF WIDTH OF TIRE UPON TRACTIVE POWER *

Resistances in Pounds per Ton

Ref. No.	Description of the Road Surface.	Diameters of the Front and Rear Wheels Respectively.									
		3′ 6″ and 3′ 10″.		3′ 6″ and 3′ 10″.		3′ 8″ and 4′ 6″.		3′ 6″ and 3′ 10″.		3′ 8″ and 4′ 6″.	
		Width of the Tire.									
		1½″	4″	1½″	4″	1½″	4″	1½″	3″	1¾″	3″
1	Sod	....	....	....	....	....	....	283	239	189	228
2	Earth Road, hard	....	108	....	....	....	....	152	152	114	114
3	" " muddy	....	243	268	304	236	254	....	....	265	228
4	Sand Road, hard	199	162	171	164	141	168	....	....	....	....
5	" " deep	371	351	....	....	....	....	....	....	....	....
6	Gravel Road, good	....	....	98	117	83	80	....	....	66	76
7	Wood Block, round	51	49	61	70	35	46	....	54	28	38

the easier; while upon the soft or spongy surface the wider tire draws the easier.

Morin experimented (see § 20) with tires $2\frac{1}{2}$, $4\frac{1}{2}$, and $6\frac{1}{2}$ inches wide; and concluded that on a solid road or pavement the resistance was independent of the width of the tire, but on a compressible surface the resistance decreased as the width of the tire increased, the rate depending upon the nature of the surface.

For a further discussion of the relative merits of broad and narrow tires, see § 200–202.

18. *Effect of Speed.* The rolling resistance increases with the velocity, owing to the effect of the shocks or concussions produced by the irregularities of the road surface. This increase is less for vehicles having springs than for those not having them, and is also less for smooth road surfaces than for rough ones.

Table 5, page 17, is a summary of Morin's results (see § 20) showing the effect of a variation of speed for vehicles provided with springs. In a rough way the three speeds are $2\frac{1}{2}$, 5, and $7\frac{1}{2}$ feet per second, or about 2, 4, and 6 miles per hour respectively. According to these results the resistance on broken-stone roads increases roughly as the fourth root of the speed, and on stone-block pavement about as the square root. For springless vehicles the increase would be greater. The above is for metal tires; for pneu-

* Pamphlet by Studebaker Bros. Manufacturing Co., South Bend, Ind., 1892.

TABLE 5

EFFECT OF SPEED ON TRACTIVE POWER *

The figures give the resistance in pounds per ton

Ref. No.	Description of the Road Surface.	Stage Coach.			Carriage.		
		Walk.	Trot.	Fast Trot.	Walk.	Trot.	Fast Trot.
	Broken Stone Road:						
1	Good condition, dry and compact .	42	49	50	41	48	49
2	Very firm, large stones visible.....	59	75	81	58	73	81
3	Little moist, or little dirty.....	49	75	88	48	74	88
4	Firm, little soft mud.....	77	92	100	76	91	99
5	" ruts and much mud.....	95	108	117	93	108	116
6	Portions worn out, thick mud.....	112	127	134	110	126	132
7	Much worn, ruts 3″ deep, thick mud	146	161	169	145	160	168
8	Very bad, ruts 4″ deep, very rough	164	180	.....	162	202	.....
	Stone Block Pavement:						
9	Very smooth, narrow joints.....	32	48	55	31	47	54
10	Fair condition, dry.....	35	52	61	34	51	67
11	Moist, covered with dirt.....	35	49	56	44	60	67

matic tires there is very little increase of resistance with increase of speed.†

The preceding data refer to the effect of speed upon the tractive power after the load is in motion. It requires from two to six or eight times as much force to start a load as to keep it in motion at 2 or 3 miles per hour. The extra force required to start a load is due in part to the fact that during the stop the wheel may settle into the road surface, in part to the fact that the axle friction at starting is greater than after motion has begun, and further in part to the fact that energy is consumed in accelerating the load.

19. *Effect of Springs.* Springs decrease the tractive resistance by decreasing the concussions due to irregularities of the road surface, and are therefore more effective at high speeds than at low ones, and on rough roads than on smooth ones. Apparently no experiments have been made upon the effect of springs; but a few data on this subject may be obtained by comparing the last and the sixth columns of Table 6, page 18.

20. Results of Early French Experiments. Immediately before and shortly after the introduction of railroads, European engineers made many experiments on the force necessary to draw different vehicles over various surfaces. The experiments by Morin,* made in

* Expériences sur le tirage des voitures et sur les effets destructeurs qu'elles exercent sur les routes, executées en 1837 et 1838 par ordre du Ministre de la Guerre, et en 1839 et 1841 par ordre du Ministre des Travaux Publics, A. Morin. Paris, 1842.

† Proc. of Inst. of Mech. Engrs. (London), for 1890, Part No. 2, p. 195.

TABLE 6

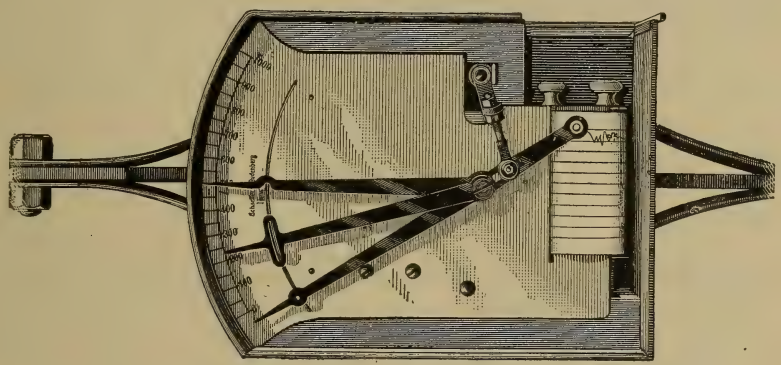
TRACTIVE RESISTANCE OF DIFFERENT VEHICLES ON VARIOUS LEVEL ROADS, AT THREE MILES AN HOUR, IN POUNDS PER TON

Ref. No.	Description of the Road Surface.	Vehicles without Springs.						Vehicles with Springs.		
		Gun Carriage. $t = 4.5''$ $a = 3''$ $D = 60''$	Freight Cart. $t = 4.5''$ $a = 2.5''$		Artillery Wagon. $t = 3''$ $a = 3''$	Freight Wagon. $t = 4.5''$ $a = 2.5''$		Stage Coach. $t = 4.5''$ $a = 2.5''$	Carriage. $t = 3''$ $a = 2''$	Wagon. $t = 2.5''$ $a = 2''$
			$D = 64''$	$D = 80''$	$d = 45''$ $D = 60''$	$d = 36''$ $D = 60''$	$d = 44''$ $D = 78''$	$d = 36''$ $D = 56''$	$d = 36''$ $D = 56''$	$d = 50''$ $D = 58''$
	Grass Plat:									
1	Very firm and dry	72	.....	.....	82	.....	.....	.....	.....	.....
2	Moderately firm	87	.....	.....	100	.....	.....	.....	.....	.....
3	A little moist	98	.....	.....	.....	.....	.....	.....	.....	.....
4	Slightly wet	140	.....	.....	160	.....	.....	.....	.....	.....
5	Very wet, no water on surface	.....	.....	.....	260	.....	.....	.....	.....	.....
	Earth Road:									
6	Very good condition, nearly dry	57	55	44	66	74	63	77	76	64
7	Covered with untrodden snow	109	105	84	125	140	120	146	.....	123
	Gravel Road:									
8	$1\frac{1}{4}''$ to $1\frac{1}{2}''$ loose gravel on firm earth	147	143	114	169	190	163	198	198	168
9	$2''$ " $2\frac{1}{2}$ " " "	172	168	134	198	225	192	233	233	198
10	$4''$ " $6''$ " " "	185	180	144	216	241	206	250	250	212
11	$4''$ " $6''$ " " and fine sand	196	190	153	247	251	217	267	290	225
	Water-bound Macadam Road:									
12	Good condition, dry and compact	32	30	24	37	40	34	42	41	35
13	Very firm, large stones visible	37	35	28	43	47	40	49	48	41
14	Little moist or little dirty	45	43	34	52	57	49	59	58	50
15	Firm, little soft mud	57	55	44	66	74	63	77	76	64
16	" ruts and much mud	70	68	54	81	90	78	95	93	79
17	Portions worn out, thick mud	83	80	64	96	107	92	112	110	94
18	Much worn, ruts 3" deep, thick mud	109	105	84	126	140	120	146	145	123
19	Very bad, ruts 4" deep, very rough	121	118	94	140	157	134	164	168	139
	Stone Block Pavement:									
20	Very smooth, narrow joints	25	23	18	29	31	26	32	31	26
21	Fair condition, dry	27	25	20	31	34	29	35	34	29
22	Moist, covered with dirt	34	33	26	40	43	37	45	44	38
	Plank Road:									
23	Thick oak bridge floor	37	35	28	43	47	40	49	48	41

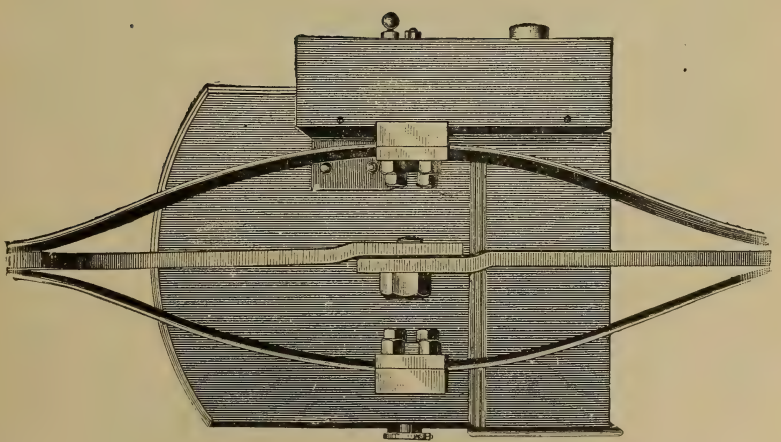
t = width of tire. a = diameter of axle. d = diameter of smaller wheel. D = diameter of larger wheel.

1837–41 for the French Government, were much the most elaborate and appear to have been made with great care. Table 6, page 18, is a summary of Morin's results showing the tractive resistance for different vehicles on various road surfaces. The table represents about 700 experiments.

21. Results of Modern American Experiments. Table 7, page 20, shows data obtained by the author. The tractive power was determined with a Baldwin dynograph, Fig. 1. The instrument consists of two long flat springs fastened together at their ends and



TOP VIEW



BOTTOM VIEW

FIG. 1.—BALDWIN DYNOGRAPH.

having their centers slightly farther apart than their ends. One end of the apparatus is attached to the wagon, and the team is hitched to the other. The pull of the team causes the centers of the flat springs to approach each other. One spring supports a graduated disk, and the other is connected to an index arm which is pivoted at the center of the disk. From one end of this index arm, the pull can be read directly from the graduated disk. There are two extra index arms—one to indicate the maximum power developed and one to indicate a rough average. The former (the upper one in Fig. 1) is simply pushed around by the main index arm and is left at the highest point. The latter (the middle arm in Fig. 1) has a transverse slot in which plays a stud on the main index arm. When making an

TABLE 7

TRACTIVE RESISTANCE ON LEVEL PAVEMENTS

Expt. No.	Location and Description of the Pavement.	Pounds per Ton.
1	Asphalt: Chicago—Calumet Ave., bet. 43d and 44th Sts.; smooth, clean, no cracks, 52° F.	37
2	Chicago—Calumet Ave., bet. 43d and 44th Sts.; smooth, clean, no cracks, 84° F.	70
3	Chicago—Washington Boul., bet. Halsted and Green Sts.; smooth, clean, no cracks, 42° F.	34
4	Brick: Champaign—University Ave., west of New St.; 3 × 9-in. brick on concrete, corners rounded, sand filler, not worn, clean.	17
5	Champaign—Second South St.; same as No. 4, except newer and covered with ½-in. of dust.	31
6	Champaign—First South St.; same as No. 4, except cement filler, just completed.	22
7	Chicago—Peoria St., between Washington and Randolph; 2¼ × 8-in. brick on concrete, pitch filler, new.	24
8	Chicago—Laurel St. Stock Yards; 3 × 8-in. brick on gravel and cinders, sand filler, corners not rounded.	37
9	Chicago—Exchange Ave., Stock Yards; 2¼ × 8-in. brick on sand and old macadam, tar filler, new.	25
10	Granite block: Chicago—Exchange Ave., Stock Yards; smoothly dressed 3 × 9-in. blocks on concrete, joints ¼ in., tar filler, not worn.	29
11	Chicago—Randolph St., between Desplaines and Halsted; smoothly dressed blocks on concrete, pitch filler, new.	30
12	Chicago—Halsted St., between Randolph and Washington; ordinary granite, 9 years old.	36
13	Macadam: Chicago—Michigan Ave., between 42d and 43d Sts.; granite top, no dust, no mud.	18
14	Plank road: Chicago—Packer's Ave., Stock Yards; oak plank, 3 × 12-in., nearly new.	32
15	Exactly same as above after worn down ¼ in. in many places, clean.	38
16	Substantially same as above; covered with ½-in fine loose dirt	40
17	Steel wheelway: Chicago—Transit Ave., Stock Yards; 8-in. 11¼ lb. channel on 2 × 8-in. pine, that on macadam, covered with ⅛-in. powdered stone.	40
18	Same when scraped with a shovel.	19
19	Same when covered with ½-in. fine dust.	28
20	Wood block: Rectangular blocks 3 × 12-in. considerably worn.	36
21	Cylindrical cedar block covered with ⅜-in. silica pea gravel	90
22	Exactly same as above covered with ¼-in. crushed gravel.	50
23	Cylindrical cedar block; clean, blocks slightly convex on top	53
24	Cylindrical cedar block on 2-in. plank and 2 in. of sand, clean, not worn.	37
25	Same as above; clean, slightly worn.	51
26	Same as above; clean, considerably worn.	54

experiment the main index arm is continually in motion, and the position of the auxiliary arm roughly indicates the average power exerted. The end of the index arm opposite the graduated arc records the amount of tractive resistance upon a strip of paper which is wound from one cylinder to another by clock-work located behind the lower right-hand corner of the top view of Fig. 1. The autographic record is more accurate than the indicated reading.

The wagon employed was the usual thimble-skein four-wheel farm wagon with a 2-inch tire. Experiments 3, 4, and 5 were made with wheels averaging $42\frac{1}{2}$ inches in diameter, and the remainder with wheels averaging 47 inches.

22. From a study of the preceding experiments and also others not here described, it is concluded that the average tractive resistance on different road surfaces is about as in Table 8 which is given for use in comparing different roads and pavements.

TABLE 8

STANDARD TRACTIVE RESISTANCE OF DIFFERENT ROADS AND PAVEMENTS

Ref. No.	Kind of Road Surface.	Tractive Resistance.	
		Pounds per Ton.	In Terms of Load.
1	Asphalt—artificial sheet	30– 70	$\frac{1}{67}$ – $\frac{1}{30}$
2	Brick	15– 40	$\frac{1}{133}$ – $\frac{1}{50}$
3	Cobble stones	50–100	$\frac{1}{40}$ – $\frac{1}{20}$
4	Portland cement concrete, unsurfaced	27– 30	$\frac{1}{75}$ – $\frac{1}{67}$
5	Earth roads—ordinary conditions	50–200	$\frac{1}{40}$ – $\frac{1}{10}$
6	Gravel roads	50–100	$\frac{1}{40}$ – $\frac{1}{20}$
7	Water-bound macadam	20–100	$\frac{1}{100}$ – $\frac{1}{20}$
8	Plank road	30– 50	$\frac{1}{67}$ – $\frac{1}{40}$
9	Sand—ordinary condition	100–200	$\frac{1}{20}$ – $\frac{1}{10}$
10	Stone block	30– 80	$\frac{1}{67}$ – $\frac{1}{25}$
11	Steel wheelway	15– 40	$\frac{1}{133}$ – $\frac{1}{50}$
12	Wood block—rectangular	30– 50	$\frac{1}{67}$ – $\frac{1}{40}$
13	" cylindrical	40– 80	$\frac{1}{50}$ – $\frac{1}{25}$

23. GRADE RESISTANCE. This is the force required on a grade to keep the load from rolling down the slope. It is independent of the nature of the road surface, and depends only upon its angle of inclination.

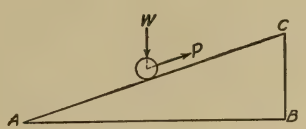


FIG. 2.

In Fig. 2, P is the grade resistance, and W is the weight of the wheel and its load. From the diagram it is easily seen that $P = W \times BC \div AC$. For all ordinary cases, AC may be considered as equal to AB, and then $P = W \times BC \div AB$.

The preceding analysis is approximate for three reasons: (1) assuming $A\,C = A\,B$, i. e., assuming the sine of inclination to be equal to the tangent; (2) assuming the normal pressure on the inclined road surface to be equal to the weight, i. e., assuming the cosine of the inclination to be unity; and (3) neglecting the fact that the hind wheels carry a greater proportion of the load on an inclination than on the level. The resulting error, however, is wholly inappreciable.

Grades are ordinarily expressed in terms of the rise or fall in feet per hundred feet, or as a per cent of the horizontal distance. If $A\,B$ be 100 feet, then the number of feet in $B\,C$ is the per cent of the grade; and therefore the grade resistance is equal to the load multiplied by the per cent of the grade. Or the grade resistance is equal to 20 lb. per ton multiplied by the per cent of the grade.

24. Power of a Horse. The horizontal pull which a horse can exert depends upon its weight, its build, the method of hitching, the foothold afforded by the surface, the speed, the length of duration of the effort, the rest-time between efforts, and the tax upon the future efficiency of the horse. The chief of these are the weight, the speed, and the length of the effort.

Horses vary in weight from 800 to 1,800 lb. The larger horses do not usually travel more than $2\frac{1}{2}$ or 3 miles per hour. With reasonably good footing a horse can exert a pull equal to one tenth of its weight at a speed of $2\frac{1}{2}$ miles per hour ($3\frac{2}{3}$ feet per second) for 10 hours per day for 6 days per week and keep in condition. This is a common rate of exertion by farm horses in pulling plows, mowers, and other agricultural implements. On this basis a 1500-lb. horse would develop 550 foot-pounds per second (the conventional horse-power), and 16,500,000 foot-pounds per day. This may be considered about the limit of endurance. A lighter horse will exert a proportionally less force. If the time of the effort is decreased, the draft may be proportionally increased; or if the speed is increased, the draft must be decreased in a like proportion. In other words, the foot-pounds of energy that can be developed per day by any particular horse is practically constant.

The maximum draft for a horse is about half of its weight, although horses have been known to exert a pull of two thirds of their weight. Most horses can exert a tractive power equal to half their weight, at a slow walk for about 100 feet. On the road in emergencies, as in starting the load or in overcoming obstacles, a horse may be expected to exert a pull equal to half its weight, but

at this rate it would develop a day's energy in about 2 hours; and consequently if it is expected to work all day, it should not be called upon to exert its maximum power except for a short time. Similarly, a horse can exert a draft equal to one quarter of its weight for a longer time. The working tractive power of a horse may be taken as one tenth of its weight, with an ordinary maximum of one quarter, and in great emergencies a maximum of one half its weight.*

25. Increasing the number of horses does not increase the power proportionally—for somewhat obvious reasons. It is stated that for a two-horse team the efficiency of each horse is about 95 per cent; for a three-horse team, about 85 per cent. Of course such data are not much more than guesses.

26. Effect of Grade. The effective tractive power of a horse upon an inclined road surface is decreased by the fact that the horse must lift his own weight up the grade. If T = the tractive power, W = the weight of the horse, t = the tractive power on the level in terms of the weight of the horse, and g = the rise of the grade per unit of horizontal distance, then, with sufficient accuracy,

$$T = tW - gW = (t - g)W. \quad . \quad . \quad . \quad . \quad . \quad (1)$$

If it be assumed that the average working tractive power of the horse is one tenth of its weight, then t = 10 per cent; and equation (1) shows that on a 1 per cent grade the horse can exert an effective tractive power of 9 per cent of its weight, and also that it will be able to carry its own weight up a 10 per cent grade. If it be assumed that the horse exerts a tractive power equal to 20 per cent of its weight, then equation (1) shows that on a 10 per cent grade it can take its own weight up and in addition exert a tractive power of 10 per cent of its weight upon the load. By assigning values to t and g, equation (1) readily shows the effective draft of a horse upon any grade.

Equation (1) is not mathematically correct, since it assumes that the weight of the horse is always normal to the road surface. However, the formula is sufficiently accurate for use in comparing the relative tractive power of a horse on different grades (§ 27). At best such a formula can be only approximate, since the tractive power varies greatly with the foothold.

* For the results of experiments made at the Kansas State Agricultural College, showing that, a horse in pulling from 500 to 1500 feet probably exerted from 26 to 42 per cent of its weight, see *Engineering and Contracting*, Vol. 38 (1912), p. 515.

27. Maximum Load on a Grade. On a grade the effective tractive power as given by equation (1) is used up in moving the load over the road surface and in lifting the load vertically. If L = the load, and μ the coefficient of road resistance, then

$$(t - g)W = \mu L + gL, \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

and

$$L = \frac{t - g}{\mu + g} W. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Equation (3) gives the load that a horse can draw up any grade.

Table 9 is computed from equation (3) for a value of t equal to one tenth of the weight of the horse. The top line of the table shows the loads that a horse can draw on the level on the various road surfaces; and any column of the table shows the load that a horse can pull on any grade for that particular road surface.

As showing the different effects of grades upon different roads, notice that on a muddy earth road a 1 per cent grade reduces the load less than one tenth, while on asphalt a 1 per cent grade reduces the load more than one half; or, again, notice that with a 5 per cent grade, on iron rails the load is less than one twentieth of the load on the level, while on the best earth road the load is one fifth of that on the level.

TABLE 9

EFFECT OF GRADE UPON THE LOAD A HORSE CAN DRAW ON DIFFERENT ROADS

The Load is in terms of the Weight of the Horse

Ref. No.	Rate of Grade. Per Cent.	Iron Rails. $\mu = \frac{1}{200}$.	Sheet Asphalt. $\mu = \frac{1}{100}$.	Broken Stone. $\mu = \frac{1}{60}$.	Stone Block. $\mu = \frac{1}{50}$.	Earth Road.		
						Best. $\mu = \frac{1}{33}$.	Spongy. $\mu = \frac{1}{20}$.	Muddy. $\mu = \frac{1}{10}$.
1	0	20.00	10.00	6.00	5.00	3.00	2.00	1.00
2	1	6.00	4.50	3.33	3.00	2.09	1.50	0.91
3	2	3.20	2.67	2.16	2.00	1.51	1.14	0.67
4	3	2.00	1.75	1.49	1.40	1.11	0.87	0.54
5	4	1.33	1.20	1.05	1.00	0.82	0.66	0.43
6	5	0.91	0.83	0.75	0.71	0.60	0.50	0.33
7	6	0.62	0.57	0.52	0.50	0.43	0.36	0.25
8	7	0.40	0.38	0.34	0.33	0.29	0.25	0.18
9	8	0.24	0.22	0.21	0.20	0.18	0.15	0.11
10	9	0.15	0.10	0.09	0.09	0.08	0.07	0.05
11	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 9 shows the load a horse can draw upon different grades and different road surfaces when exerting a uniform pull equal to

one tenth of its weight. If we desire to know the maximum load which a horse can draw up any grade, we must insert in equation (3) the maximum value of t and compute the corresponding value of L. The value of t to be used in this computation will depend upon the length of the grade and upon the frequency with which it occurs. If the grade is only a few hundred feet long, it will probably be safe to assume a pull equal to one fourth of the weight of the horse; but this value should be assumed only for the maximum grade, since such pulling is too exhausting for continuous work.

Table 10 presents the same data as Table 9, but in a slightly different form.

TABLE 10

LOAD WHICH A HORSE CAN DRAW ON A GRADE IN TERMS OF THE LOAD ON THE LEVEL WHEN EXERTING A UNIFORM FORCE EQUAL TO ONE TENTH OF ITS WEIGHT

Ref. No.	Rate of Grade, Per Cent.	Iron Rails. $\mu = \frac{2}{100}$.	Sheet Asphalt. $\mu = \frac{1}{100}$.	Broken Stone. $\mu = \frac{1}{60}$.	Stone Blocks. $\mu = \frac{1}{30}$.	Earth Road.		
						Best. $\mu = \frac{1}{33}$.	Spongy. $\mu = \frac{1}{20}$.	Muddy. $\mu = \frac{1}{15}$.
1	0	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2	1	0.30	0.45	0.56	0.60	0.62	0.75	0.91
3	2	0.16	0.27	0.36	0.40	0.50	0.57	0.67
4	3	0.10	0.18	0.25	0.28	0.37	0.44	0.54
5	4	0.07	0.12	0.17	0.20	0.27	0.33	0.43
6	5	0.04	0.08	0.12	0.14	0.20	0.25	0.33
7	6	0.03	0.06	0.08	0.10	0.14	0.18	0.25
8	7	0.02	0.04	0.06	0.06	0.10	0.12	0.18
9	8	0.01	0.02	0.04	0.04	0.06	0.08	0.11
10	9	0.01	0.01	0.02	0.02	0.03	0.04	0.05
11	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00

28. The maximum load which a horse can draw upon any road, particularly upon the steepest grade, is not, however, necessarily proportional to the rate of grade and to the resistance, since the pull that a horse can exert depends upon the foothold. Owing to the danger of slipping on steep grades, particularly when the road is wet or icy, it is not customary to lay sheet asphalt on grades of more than 4 per cent, or ordinary stone blocks on grades of more than 10 per cent. On steeper grades, special forms of stone blocks are sometimes employed to increase the tractive power by affording better foothold for the horses.

29. TRAVEL CENSUS. A knowledge of the use made of a road or pavement has an important bearing on questions of construction,

maintenance, and cleaning. The travel determines the amount of money that may economically be spent in reconstruction, and also fixes the width and character of the improved portion. The use made of the road or street is necessary to determine the amount of service obtained from any particular road surface. Further, the cost of cleaning a pavement depends upon the character of the surface and the travel; and unless the latter is known, it is impossible to make any instructive comparison between the cost of cleaning different surfaces.

30. History. It is surprising that but few travel censuses have ever been taken. Except in France, not much attention has been given to this subject in Europe. The French engineers have made a very careful study of the amount and effect of travel on the rural roads. Previous to 1844 travel data had been collected in certain localities; but from 1844 to 1903 ten censuses of national scope were taken, and it is planned to take one every 10 years.

The results of the French observations are not of much value in America because of the difference in conditions; and results before about 1906 are not of much value because of the recent introduction of the automobile.

31. American Roads. The Massachusetts Highway Commission in 1909 had a travel census taken upon state-aid highways for 14 hours per day for seven days at 238 stations, and in 1912 a similar count was made at 156 stations, and in 1915 at 192 stations. At the same time a travel census was taken at a number of points on the roadways of the Metropolitan and the Boston Park Systems. The methods and results are presented in the respective annual reports.

The observer separated motor-driven vehicles into three classes, and horse-drawn into four. These classes and the assumed weight of each (taken according to the prevailing practice in Great Britain) are as follows:

Motor-Driven Vehicles:	Weight
Runabouts	1.35 tons
Touring cars	2.23 "
Trucks	6.25 "
Horse-Drawn Vehicles:	
1-horse, light	0.36 "
1- " heavy	1.12 "
2 or more horses, light	0.54 "
2 " " heavy	2.46 "

In the first three years motor travel on the rural roads increased 130 per cent, and in the second three years 150 per cent; while the horse-drawn vehicles decreased almost exactly 20 per cent in each period. In 1912 the motor-driven vehicles were 63 per cent of the horse-drawn, but in 1915 they were 497 per cent. The total travel increased about in proportion to the number of motor cars registered. As the number of motor cars in this country is rapidly increasing (for example, the number made in 1916 was 80 per cent greater than in 1915), it is likely that travel on public highways will continue to increase.

A summary of this census for a few roads is shown in Table 11; and incidentally this table also shows the use of travel census data in determining the unit cost of maintenance. The wide variation in the cost of maintenance of these roads is probably due to differences in the age or character of the surface and to differences in the character of the traffic.

TABLE 11

TRAVEL AND COST OF REPAIRS ON MASSACHUSETTS STATE-AID ROADS

Road.	Motor-Drawn Vehicles.			Horse-Drawn Vehicles.				Total Traffic.		Cost of Maintenance.	
				Single Horse.		Two or More.					
	Runabout.	Touring Car.	Trucks.	Light.	Heavy.	Light.	Heavy.	Tons per Day.	Tons per Year (300 Days).	Per Mile per Year.	Cents per Ton-Mile per Year.
Ashley	14	65	4	70	16	5	14	271	81 150	$ 266	0.38
Beverly (No. 1)	60	278	8	66	46	4	12	1 618	485 220	1 104	0.23
Hamilton	86	334	31	75	39	2	27	1 199	359 730	200	0.06
Lynn	194	1 365	13	28	19	1	14	3 468	1 040 430	1 081	0.10
Medford-Somerville	44	121	49	47	198	2	193	1 332	399 570	1 031	0.26
Milton	15	50	0	30	77	2	88	1 140	342 210	592	0.17
Sangus	15	58	78	25	190	3	65	1 022	306 660	1 334	0.44
Shrewsbury	76	407	17	64	60	4	36	1 305	391 550	510	0.13
Truro	7	63	1	15	14	1	3	186	55 770	143	0.25
Weston	115	533	30	167	98	5	59	1 918	575 280	1 040	0.18

The use of a travel census in determining the character of a road surface fitted to particular traffic conditions is incidentally illustrated in Table 26, page 177.

32. In 1906 the Illinois Highway Commission took a census of travel at 71 stations at various times during one year.* Observa-

* Annual Reports for 1906 and 1907.

tions were made of only the number of vehicles without distinction as to their character or weight. Twelve of the roads had about 75 vehicles per day, twenty-seven about 145, and ten about 250. The results seem to show that there is no relation between the travel on a road and the population of the near-by town; or, in other words, that there are roads in the vicinity of even very small towns that have as much travel as roads near large cities.

33. In the summer of 1917 the Iowa Highway Commission took a census of travel on a few of the main roads. Observations were made at each station for ten days; and all vehicles were actually weighed. A record is to be made of farm traffic, of town and city traffic, and of tourist travel, with the hope of securing data for an equitable apportionment of road expenditures. A preliminary report on observations made during the tourist season at eight stations on an earth-surface tourist highway leading into important market centers, showed 3 per cent tourist travel, 87 per cent interurban traffic, and 10 per cent farm traffic.

34. American Streets. The first travel census in the United States was carried out by the Barber Asphalt Co. in New York City and less elaborately in ten other cities in 1885.* The record shows the total number of vehicles and the number of tons per foot of width of pavement. The same company took a similar census in New York City in 1904.† In both cases the count was limited mainly to asphalt and granite-block pavements. Since 1913 the city of St. Louis, Mo., has taken an annual travel census—at first on business streets, but later also on residence streets.‡ In New York and St. Louis there was a very great annual increase in the amount of travel. In St. Louis from 1914 to 1915 the increase was 20 per cent, the increase in motor-driven traffic being 53 per cent and the decrease in horse-drawn 15 per cent. A few other records of various kinds have been made in several cities.

35. Classification of Traffic. The data collected in a travel census should be such that, in addition to being used for local comparisons, they should be such as to permit comparisons with data taken in other localities. There is no standard method of classifying the vehicles, or of the assumed weight of the different vehicles, or of fixing the width of the traveled way. Further, the density of travel is sometimes stated by giving simply the number of vehicles per day

* Trans. Amer. Soc. of C.E., Vol. 15 (1886), p. 123.
† *Ibid.*, Vol. 57 (1906), p. 181–90.
‡ *Engineering News*, Vol. 76 (1916), p. 832–34.

or per year; but usually by giving the number of tons per year per foot of width. The unit for comparing the cost of maintenance is either the tons per year per foot of width or the ton-miles per year.

The classification and weights of the vehicles in the Massachusetts census are shown in § 31. Apparently the width of the traveled way was taken as the full width of the improved portion,—as it probably is in a narrow rural road. For a somewhat similar classification and schedule of weights employed by several road and pavement constructing companies, see page 149 of the 1912 Proceedings of the American Society of Municipal Improvements.

36. *Weight of Vehicles.* The following classification and schedule of weights has been recommended.* The weight of the horse is to be considered as a part of that of the vehicle; and the ton is 2,000 pounds.

Horse-Drawn Vehicles		Motor-Driven Vehicles	
Number of Horses.	*Weight, tons.*	*Style of Automobile.*	*Weight, tons.*
Single horse without vehicle	0.50	Motorcycle or bicycle	0.15
1-horse vehicle, light	1.20	2-passenger automobile	1.30
1-horse vehicle, heavy	2.00	Over 2-passenger automobile	2.20
2-horse vehicle, light	2.00	Freight motor-truck, light	6.30
2-horse vehicle, heavy	4.00	" " medium	6.00
3-horse vehicle	5.00	" " heavy	8.50
4-horse vehicle	6.00		

37. *Width of Traveled Way.* The effective traveled width of a street is sometimes taken as 3 feet less than the width between curbs. In many cases, particularly adjacent to car tracks and where automobiles are parked along the curb, most of the travel is concentrated upon a comparatively narrow portion of the pavement.† The results should be stated in tons per foot of total width, and also in tons per foot of maximum traveled width.

If the several classes of traffic are segregated into different lines of travel, the details should be stated.

38. *Diversion of Travel.* In any investigation of traffic conditions preliminary to any improvement in either the location or the surface of a road, careful attention should be given to the probable effect of the improvement in diverting travel to the road or street. Some-

* W. H. Connell, Chief of Bureau of Highways, Philadelphia, *Engineering and Contracting*, Vol. 47 (1917), p. 227.

† For diagrams showing this concentration, see *Engineering News*, Vol. 78 (1917), p. 201–2.

times a small change in the condition of the road makes a radical change in the amount and character of the travel.

39. Weight and Width of Vehicles. Formerly the only excessive loads hauled over rural roads or city streets were heavy pieces of building or bridge material, machinery, etc., hauled on horse-drawn vehicles, and steam traction-engines; but as these vehicles were not very numerous and as the speed was low, no serious harm was done, particularly where traction engines were required to remove or cover the mud lugs. In the last ten years the advent of heavy high-speed motor trucks has greatly increased the loads and speeds of vehicles using the highways. Certain types of motor vehicles now in use are too heavy for the present roads or pavements, and much damage is being done; and furthermore the number and weight of such vehicles is rapidly increasing. It is inequitable and impracticable to reconstruct all or even many of the roads and pavements so as to enable them to carry safely such motor-driven vehicles. Therefore special taxes are being levied upon heavy motor-driven vehicles, partly to make them partially pay for the damage done to the highways, but chiefly to prevent further increase in their number and weight. Some of the states have laws regulating the load per width of tire and also the speed, and some regulate also the diameter of the wheel.* The following is from an ordinance recently passed in New York City.†

License Schedule for Motor Trucks in New York City

"(*a*) Vehicles carrying or intending to carry a total gross load of 6,000 lb. or less upon any wheel shall be charged the following annual license fee:

Load in Pounds per Inch Width of Tire.	*License Fee for Each Vehicle.*
700 or less	$1
751 to 800	3
801 to 850	6
851 to 900	12
901 to 950	25
951 to 1 000	50

"(*b*) In addition to the fees provided in subdivision (*a*), further fees shall be charged for loads greater than 6,000 lb. upon any wheel, but not exceeding 10,000 lb., as follows:

* For the laws regulating motor trucks in a number of states and cities, see *Engineering News*, Vol. 76 (1916), p. 938–39.

† *Engineering Record*, Vol. 73 (1917), p. 790.

Weight in Pounds per Wheel.	*License Fee for Each Vehicle.*
6 000 to 6 500	$75
6 501 to 7 000	110
7 001 to 7 500	150
7 501 to 8 000	200
8 001 to 8 500	300
8 501 to 9 000	500
9 001 to 9 500	750
9 501 to 10 000	1 000

"For loads greater than 10,000 lb. per wheel, license fees shall be charged for each vehicle at the additional rate of $500 for each 1,000 lb. per wheel increase in weight, provided no load greater than 1,000 lb. per inch width of wheel shall in any case be permitted, except as specified in subdivision (*d*).

"In lieu of the fees hereinabove provided for in subdivisions (*a*) and (*b*) for loads of 6,000 lb. or more on any wheel, special permits may be issued for single trips and fees charged therefor at the rate of 10 per cent of the fees therein provided, except that no single fee shall be less than $25.

"(*c*) Vehicles 6 feet 6 inches or more in width over all shall be charged, in addition to the fees specified in subdivision (*a*) and (*b*), the following annual fee:

Width of Vehicle	License Fee *for each inch in width in excess of 6 feet 6 inches.*
6 feet 6 inches to 7 feet 0 inches	$5
7 " 0 " 7 " 6 "	10
7 " 6 " 8 " 8 "	15
8 " 0 " 8 " 6 "	20
8 " 6 " 9 " 6 "	25

"(*d*) In lieu of the fees provided in subdivision (*c*) for excess width of vehicle, special permits for single trips may be granted upon payment of single fee of not less than $10."

ART. 2. ROAD ADMINISTRATION

41. ADMINISTRATIVE UNIT. In this country until recently, the management of roads rested upon local authorities, either those of townships or counties. In those cases in which the administration of road affairs was nominally in the hands of the county authorities, nothing was usually done except to divide the county into road districts and virtually transfer all authority to local officials appointed for that purpose. Apparently it is impossible to secure either good roads or an efficient road administration by the action of officials who have only local authority, and who are necessarily swayed by purely local, if not individual, interests. This is not peculiar to

America, since great difficulties have always been encountered in maintaining a system of public highways by any locally governed community.

The fundamental difficulty is that the small administrative unit makes it impossible to secure efficient supervision, since the time necessarily required in road administration is but an incident among private or official duties. Another difficulty is that the official is usually elected for political reasons, rather than for his ability in matters relating to the roads. A further difficulty is that the tenure of office is short, and successive officials have conflicting views as to road administration and road improvement.

Another objection to the small administrative unit is the improbability of the district's having suitable machinery in sufficient quantity to effectively and economically care for the roads.

42. State Aid.—In 1891 the state of New Jersey inaugurated a new departure in road administration in the United States—that of state aid in road construction. In 1917 all of the states except Mississippi and South Carolina had adopted some form of state aid. The fundamental principle of state aid is that some roads are built at the joint expense of the state and local authorities. The states differ greatly as to (1) the proportion paid by the state, (2) the amounts paid by the county, township, and abutting property, (3) the amount and the method of the supervision over the construction, and (4) the authority that maintains state-aid roads.

The adoption of state aid led to the establishment of state highway departments in many of the states; but to participate in federal aid (see § 45) it was necessary for a state to have a state highway department, and hence all of the states now have such departments.

One of the most important factors in bringing about the rapid adoption of state aid and state supervision, has been the introduction of the automobile and the consequent development of greater interest in good roads.

43. Table 12 gives data concerning road improvement in the several states.

44. The principle of state aid is defended on the ground that (1) it secures centralized, and therefore more efficient, control; (2) makes the wealth of the city bear part of the expense of maintaining the country roads; and (3) compels the railroads and other state-wide corporations to bear part of the expense of local improvements. The chief advantage of state aid is that it secures uniform and more intelligent supervision than is possible—on state-aid roads at least—

TABLE 12

Road Mileage and Road Expenses in the Several States

State.	Miles of Rural Public Roads.			Year Original State-Aid Law Passed.	State Aid in in 1915.	Total Cash Expenditures in 1915.
	Total Surfaced Roads in State.	Total Public Rural Roads in State.	Percentage of Surfaced Roads in 1915.			
Alabama	5 915	55 446	10.7	1911	$126 134	$4 283 207
Arizona	350	12 075	2.9	1909	476 178	1 076 178
Arkansas	1 200	50 743	2.3	1913	25 000	2 803 000
California	13 000	61 038	21.3	1895	8 301 149	20 753 281
Colorado	1 750	39 691	4.4	1909	203 000	2 193 000
Connecticut	3 200	14 061	22.7	1895	2 084 944	3 484 944
Delaware	300	3 674	8.0	1903	31 000	397 500
Florida	3 500	17 995	19.4	1915	1 135	5 501 135
Georgia	13 000	84 770	15.3	1908	.....	3 700 000
Idaho	950	23 109	4.1	1905	200 000	1 974 636
Illinois	11 000	94 141	11.7	1905	818 638	9 263 995
Indiana	27 000	63 370	42.6	1917	.....	13 000 000
Iowa	1 000	106 847	1.0	1904	80 935	13 606 299
Kansas	1 250	111 536	1.1	1911	10 000	5 510 000
Kentucky	13 000	57 916	22.1	1912	573 715	3 122 430
Louisiana	2 250	24 562	9.1	1910	144 821	3 569 709
Maine	3 000	25 528	11.7	1901	1 009 345	3 293 902
Maryland	2 950	16 458	17.9	1898	3 330 000	5 630 000
Massachusetts	8 800	18 681	46.6	1892	2 634 567	6 557 279
Michigan	8 600	74 089	11.6	1905	975 000	10 174 738
Minnesota	5 500	93 500	5.9	1905	1 580 000	8 292 000
Mississippi	2 500	45 778	5.5	.....	.....	2 900 000
Missouri	8 000	96 124	8.3	1907	369 189	8 369 189
Montana	775	39 204	2.0	1913	18 346	3 676 318
Nebraska	500	80 338	.6	1911	120 000	3 520 000
Nevada	75	15 000	.5	1911	.....	250 000
New Hampshire	1 800	14 020	12.8	1903	666 339	2 363 414
New Jersey	4 600	14 817	31.0	1891	1 163 308	7 163 584
New Mexico	450	11 873	3.8	1909	152 122	584 919
New York	17 500	80 112	21.8	1898	13 983 769	24 255 648
North Carolina	6 500	50 758	12.8	1901	10 000	5 510 000
North Dakota	1 100	68 000	1.6	1909	.....	2 500 700
Ohio	30 920	86 453	35.8	1904	3 442 604	12 975 688
Oklahoma	300	107 916	.3	1911	10 000	3 410 000
Oregon	7 780	36 819	21.1	1913	230 000	6 182 000
Pennsylvania	9 883	91 556	10.8	1903	6 541 257	12 541 257
Rhode Island	1 246	2 121	58.8	1902	204 119	594 119
South Carolina	3 500	42 220	8.3	.....	.....	1 000 000
South Dakota	850	96 306	.9	1911	.....	1 450 000
Tennessee	8 625	46 050	18.7	1915	3 500	3 503 500
Texas	12 000	128 960	9.3	1917	.....	9 500 000
Utah	1 053	15 000	7.0	1909	121 000	1 213 100
Vermont	3 478	15 082	23.1	1898	485 145	1 475 145
Virginia	4 760	53 388	8.9	1906	526 645	4 018 399
Washington	5 460	42 428	12.8	1905	1 435 020	6 670 702
West Virginia	1 200	32 024	3.7	1909	9 212	2 759 212
Wisconsin	14 050	75 702	18.5	1911	1 389 515	9 960 980
Wyoming	500	14 381	3.5	1911	5 000	441 291
Total	276 920	2 451 660	11.3	.....	53 491 651	266 976 399

with a smaller administrative unit; and besides the standards set on state-aid roads tend to become the ideals for the other roads.

45. National Aid. In 1916 Congress passed a law granting to the several states federal aid in the construction of roads, which was another new departure in road administration in this country. The law appropriated $5,000,000 for federal aid in 1917, and provided to increase the amount $5,000,000 each year until in 1921, when the appropriation will be $25,000,000. The U. S. Department of Agriculture may deduct 3 per cent for administrative expenses, and the remainder is divided among the several states as follows: One third in proportion to the areas of the states, one third in proportion to the mileage of star and rural mail routes in the states, and one third in proportion to the population according to the preceding federal census. The federal money can be used to pay not to exceed one half of the total cost of the construction of any road or system of roads, the plans for which have been previously approved by the proper federal authority. Table 13, pages 36–37, shows the official figures employed in making the distribution, and the amounts for each state in 1917.

In Europe nearly all countries give national aid in some form for building roads.

46. Classification of Roads. It has long been known by close students that the problems of road administration would be greatly improved if the roads were classified according to their importance, into state, county and township roads, or into county, township and neighborhood roads, the roads of each class to be under a corresponding administrative authority. One of the incidental, but not unimportant, results of the adoption of the state aid has been the classification of the wagon roads. It has been found that 10 to 15 per cent of the roads carry from 80 to 90 per cent of the travel. These principal roads are called state or county roads, and are the ones upon which the state aid is expended, either directly or indirectly under the supervision of state authorities.

The modification of the state road laws incident to the introduction of the principle of state aid has usually resulted in giving to some county authority supervision over township road officials.

47. Road Taxes. How shall the expense of constructing and maintaining roads be distributed? This question has been answered in various ways in different parts of this country and in different countries of Europe. There are three forms of road taxes which have long been in use; viz.: (1) a tax upon the traveler, (2) a cap-

itation tax, and (3) a property tax. The first leads to toll roads; and the second is usually called a poll tax.

In 1901 the State of New York introduced a method of raising revenue for road purposes, viz.: a license for operating automobiles. For present purposes this will be referred to as the automobile road tax.

48. Toll Roads. These are conducted on the theory that the travelers over a road are the recipients of its benefits and should pay for its support. Toll roads are justifiable only in a new country where the amount of taxable property is small, and where for long stretches of territory there are few inhabitants, since such roads induce the investment of capital that possibly the pioneer or the new community could not afford; and even under these conditions they are practicable only where there is considerable traffic. In early times the government collected the toll and used it for the maintaining and extension of the road; but later toll roads were usually in the hands of private capitalists.

Toll roads are objectionable owing to the proportionally great expense of collecting the revenue, and owing to the fact that they are managed solely with reference to securing returns upon the capital invested and without regard to the interests of the public. The only remedy for the evils of the system is for the public to support the roads. Roads are an indispensable public convenience —a benefit to every citizen, whether a direct user of the road or not,— and consequently should be maintained by a universal tax. At present the toll system is regarded as unwise for both economic and political reasons; and toll roads have almost entirely been abolished both in this country and in Europe.

49. Poll Tax. Notwithstanding the fact that most writers on political economy consider a capitation tax an undesirable form of taxation, nearly all of the states levy a poll tax for road purposes. Apparently it is the only capitation tax in this country. It is not wise to occupy space here to inquire into either the wisdom or reason for this form of road tax.

Almost universally the law permits the payment of the poll road-tax in money or labor, and it is usually paid in labor. In the poorer and less populous states, this tax is nearly the sole support of the road system. In many states there are numerous exemptions, and in all states the tax is difficult to collect, and consequently the poll tax is an unimportant element in road construction and maintenance.

TABLE 13

Apportionment of Federal Aid for Road Construction

State.	Area as of 1910 United States Census.		Population as of 1910 United States Census.		Star and Rural Routes, June 30, 1916.		Percentage Apportionment.	Sum Apportioned in 1917.
	Square Miles.	Per Cent.	Population.	Per Cent.	Miles.	Per Cent.		
Alabama	51 998	1.7180	2 138 093	2.3331	29 615	2.3911	2.1474	$104 148.90
Arizona	113 956	3.7650	204 354	.2230	3 096	.2500	1.4126	68 513.52
Arkansas	53 335	1.7621	1 574 449	1.7181	20 245	1.6346	1.7049	82 689.10
California	158 297	5.2300	2 377 549	2.5944	18 823	1.5198	3.1147	151 063.92
Colorado	103 948	3.4344	799 024	.8719	10 781	.8704	1.7256	83 690.14
Connecticut	4 965	.1640	1 114 756	1.2164	6 721	.5426	.6410	31 090.44
Delaware	2 370	.0783	202 322	.2208	2 566	.2072	.1688	8 184.37
Florida	58 666	1.9383	752 619	.8213	8 706	.7029	1.1542	55 976.27
Georgia	59 265	1.9581	2 609 121	2.8471	43 397	3.5039	2.7697	134 329.48
Idaho	83 888	2.7716	325 594	.3553	7 594	.6131	1.2467	60 463.50
Illinois	56 665	1.8722	5 638 591	6.1529	69 860	5.6405	4.5552	220 926.23
Indiana	36 354	1.2011	2 700 876	2.9472	52 619	4.2484	2.7989	135 747.62
Iowa	56 147	1.8554	2 224 711	2.4277	58 943	4.7590	3.0139	146 175.60
Kansas	82 158	2.7144	1 690 949	1.8452	53 240	4.2986	2.9527	143 207.40
Kentucky	40 598	1.3413	2 289 905	2.4988	27 113	2.1891	2.0097	97 471.91
Louisiana	48 506	1.6026	1 656 388	1.8075	9 458	.7636	1.3912	67 474.66
Maine	33 040	1.0916	742 371	.8101	13 566	1.0953	.9990	48 451.50
Maryland	12 327	.4073	1 295 346	1.4135	11 194	.9038	.9082	44 047.22
Massachusetts	8 266	.2731	3 366 416	3.6735	7 698	.6215	1.5227	73 850.95
Michigan	57 980	1.9156	2 810 173	3.0665	49 981	4.0354	3.0058	145 783.72
Minnesota	84 682	2.7978	2 075 708	2.2650	46 384	3.7450	2.9360	142 394.06

Mississippi	46 865	1.5484	1 797 114	1.9610	24 646	1.9899	1.8331	88 905.84
Missouri	69 420	2.2936	3 293 335	3.5937	57 108	4.6109	3.4994	169 720.41
Montana	146 997	4.8566	376 053	.4104	10 065	.8126	2.0265	98 287.19
Nebraska	77 520	2.5612	1 192 214	1.3010	33 964	2.7422	2.2015	106 770.81
Nevada	110 690	3.6571	81 875	.0893	2 935	.2370	1.3278	64 398.30
New Hampshire	9 341	.3086	430 572	.4698	6 444	.5203	.4329	20 996.62
New Jersey	8 224	.2717	2 537 167	2.7686	7 708	.6223	1.2209	59 212.68
New Mexico	122 634	4.0517	327 301	.3572	5 716	.4615	1.6235	78 737.81
New York	49 204	1.6254	9 113 614	9.9449	48 773	3.9379	5.1695	250 720.27
North Carolina	52 426	1.7321	2 206 287	2.4075	36 358	2.9355	2.3584	114 381.92
North Dakota	70 837	2.3404	577 056	.6297	21 548	1.7398	1.5700	76 143.06
Ohio	41 040	1.3559	4 767 121	5.2019	61 968	5.0033	3.8537	186 905.42
Oklahoma	70 057	2.3146	1 657 155	1.8083	37 145	2.9991	2.3740	115 139.00
Oregon	96 699	3.1944	672 765	.7341	11 621	.9383	1.6224	78 687.37
Pennsylvania	45 126	1.4909	7 665 111	8.3643	54 638	4.4115	4.7556	230 644.17
Rhode Island	1 248	.0412	542 610	.5921	1 093	.0882	.2405	11 665.71
South Carolina	30 989	1.0238	1 515 400	1.6536	21 851	1.7642	1.4806	71 807.64
South Dakota	77 615	2.5643	583 888	.6372	22 362	1.8055	1.6690	80 946.02
Tennessee	42 022	1.3884	2 184 789	2.3841	40 731	3.2886	2.3537	114 153.48
Texas	265 896	8.7850	3 896 542	4.2520	62 181	5.0205	6.0191	291 927.81
Utah	84 990	2.8080	373 351	.4074	3 806	.3073	1.1742	56 950.15
Vermont	9 564	.3160	355 956	.3884	8 777	.7086	.4710	22 844.47
Virginia	42 627	1.4084	2 061 612	2.2497	31 045	2.5066	2.0549	99 660.71
Washington	69 127	2.2839	1 141 990	1.2462	11 350	.9164	1.4822	71 884.28
West Virginia	24 170	.7986	1 221 119	1.3325	14 417	1.1640	1.0984	53 270.46
Wisconsin	56 066	1.8524	2 333 860	2.5467	43 854	3.5408	2.6466	128 361.07
Wyoming	97 914	3.2350	145 965	.1593	4 844	.3911	1.2618	61 196.82
Total	3 026 719	100.0000	91 641 197	100.0000	1 238 548	100.0000	100.0000	4 850 000.00

50. Property Tax. There are three forms of the property road tax: the special assessment, the direct tax, and the general tax.

In many states when any considerable road improvement is contemplated, part or all of the cost of the same is laid as a special tax or assessment on all real estate within some certain distance of the improvement. In Indiana at one time, this distance was two miles; and in Wisconsin, three. Ordinarily this tax is not uniform over the included area, but is graded according to the supposed benefits. This tax is usually payable in money.

In most of the states, the territory is divided into small units, called road districts, and a uniform road tax is laid upon all property within the district. Usually this tax may be paid in either money or labor; and when so permitted, is usually paid in labor.

In most states there is also a general property tax for road and bridge purposes, which must be paid in money.

In poorer communities the roads are cared for principally by the district road tax, which is usually paid in labor; but in wealthier communities the general property road and bridge tax (cash tax) is greater than the district road tax (labor tax).

51. Labor vs. Money Tax. In most of the states the labor tax is still regularly employed, although it is gradually disappearing. The labor-tax system was inherited from England, and is a survival of the feudal method of requiring all able-bodied men to render public service. England and France have a labor road-tax, but upon a much less extensive scale than has this country.

The roads and streets of the cities, towns, and villages are usually under the control of the municipalities, in which as a rule the labor tax does not exist; and therefore the labor-tax system applies chiefly, if not wholly, to rural communities. Further, since a very large proportion of the roads are of earth, the labor-tax system is usually applied to the construction and care of only earth roads.

It is common to assume that the labor-tax system is all wrong, and that its evils would be escaped by paying road taxes in money. The labor tax has inherent disadvantages, but many of the defects charged to it belong rather to defective administration and to the system that leaves the control of the public highways to a small locally-governed community.

The objections to the labor-tax system are: 1. The labor is indifferent and inefficient. 2. It is impossible to get the work done at the most suitable time. 3. The system allows no selection of the laborer. All of these are important considerations.

The reply to the above objections is usually about as follows: 1. The farmer is willing to pay more in labor than in money, which compensates in part, at least, for the objections to the labor-tax system. This preference is not peculiar to the American farmer. In France, if the road tax is paid in money, a reduction of 40 to 50 per cent is made; but still 60 per cent of the people prefer to pay in labor. Farmers not infrequently give more both in labor and money than is exacted as road taxes, because they are interested in better roads. 2. In many rural communities it is impossible to secure any one to do road work at reasonable wages at the most suitable season. 3. If the tax were paid in money, there is no certainty that the labor would be any more efficient. Streets are maintained under the cash-tax system, but the labor is not ideally efficient. The authority that virtually wastes the labor tax will probably also waste the cash tax.

52. The labor tax is not necessarily the cause of inferior roads, nor the cash-tax system in itself the cause of improved roads. Townships under the labor-tax system often have better roads than adjoining townships under the cash-tax system. The one thing absolutely necessary for successful road management is effective supervision of the work. Without it neither system will accomplish much, and with it either system will do reasonably well.

Many townships have changed from the labor-tax system to the cash-tax system with a marked improvement in the condition of the roads—due chiefly, if not wholly, to better administration. In these cases the public sentiment that demanded road improvement secured the change from the labor tax to the cash tax; and, consciously or unconsciously, also secured a more efficient road administration. In many of these cases the so-called cash-tax system is practically only a change in the method of administering the labor-tax system, since farmers desiring to do so are given an opportunity to work out their road taxes under the cash system. Under the labor-tax system those working upon the roads receive credit on their road taxes, while in the so-called cash system the laborer usually receives an order which is accepted as cash in paying taxes.

The labor-tax system is more objectionable with roads having a hard surface than with earth ones, since the construction of the former is more difficult and their maintenance requires intimate knowledge and constant attendance, and also since the former are built only where there is much travel and where the labor of maintenance is greater. This subject will be considered incidentally

under Maintenance in the chapters on earth, gravel, and broken-stone roads.

53. Automobile Tax. Since 1901 the several states have adopted the system of licensing automobiles as a means of securing revenue for road purposes. In 1916 the gross revenue from this source amounted to $25,865,370, of which 92 per cent was applicable for road work; and the net amount so applied was nearly 9 per cent of the total expenditures for rural roads and bridges in the United States. About 70 per cent of the total automobile revenue is expended under the supervision of the State Highway Departments.

In 1916 there was an average of 1.4 motor cars for each mile of rural public roads in the United States, and the number of motor cars is increasing, the increase in 1915 being 40 per cent and in 1916 43 per cent. The average annual registration or license fee per motor varies between the several states from 50 cents to $19.67. The tendency in all of the states is to increase the fee.

54. Comparison of Road Expenditures. From 1904 to 1915 the annual expenditures on the rural roads and bridges in the United States increased from about $80,000,000 to about $282,000,000, an increase of more than $2\frac{1}{2}$ times. During the same period the annual expenditures for state-aid road and bridge construction and maintenance increased from $2,550,000 to $53,492,000, an increase of 20 times. In 1904 the local bond issues for roads and bridges amounted to $3,530,000, but in 1915 amounted to about $40,000,000. In 1904 the expenditure for roads under state supervision was 6 per cent of the total road expenses; but in 1915 it was 30 per cent, or more than the total expenditure for roads in 1904.

In 1904 about one fourth of the total expenditures for roads and bridges was paid in labor. From 1904 to 1915, while the total expenditures for roads and bridges have increased $3\frac{1}{2}$ times, the portion from local bond issues about 11 times, and that from state aid 20 times, the portion from the labor road-tax decreased about half.

In 1904 the actual cash road and bridge expenditure in the United States averaged slightly less than $28 per mile of rural roads; but in 1915 it had increased to an average of $109 per mile of road.

55. The magnitude of the above sums shows the importance of the present road expenditures, and also the probability that such expenditures will increase greatly in the future. Road construction and maintenance is already a matter of great importance to the public and to the engineering profession, and is likely to increase rapidly.

CHAPTER II

ROAD LOCATION

58. Elements Involved. In general the determination of the best location for a road requires a study of the topographical features of the region through which the road is to pass, and also an investigation of the nature and amount of the traffic to be provided for. Viewed as a question of economics, the best location is that for which the sum of the interest on the cost of construction and of the annual cost of maintaining the road and of conducting transportation over it, is a minimum. The location of a wagon road is not, however, entirely a question of economics, since the location should be made with reference to the convenience and comfort, and perhaps also to the pleasure, of those who use it; and is frequently more of a social question than one of economics. Only the economic features of location will be considered here, and they but briefly.

However, in locating a new road, it is well to remember that the location will probably serve for many generations, and perhaps for all time, as the growing importance of the surrounding country and the location of buildings and of division lines of the land with reference to the road make it increasingly more difficult and expensive to change the location. Thus the location of a road is a field where costly errors and permanent blunders may creep in and forever fasten themselves upon the road and its users; and, worst of all, these errors become more costly as the use of the road increases.

Over most of the United States, the roads are in the main already located, and the necessity for the location of new ones does not often arise; and hence as a rule, the only application of the principles of economic location will be in the re-location of comparatively short stretches of road. The original location may have been fit and proper when the region was new and undeveloped, but the increase in the amount and the change in the character of the traffic may justify a very considerable change. There are many rural roads that could be materially improved by a careful re-location.

59. Rural roads are used by both horse-drawn and motor-driven vehicles; and strictly each class of vehicles should be considered in solving problems of road location. However, the passenger automobile need not be considered, since with the variable speed and high power of its engine, it can overcome any grade that can be economically used by horse-drawn vehicles, and since the cost of transportation by a motor-driven vehicle is small it may be neglected in computing the effect of slight differences in distance; and therefore the passenger automobile may be disregarded in problems of road location. Automobile trucks need not be considered for the same reasons as above, and also as they are much less common on typical rural roads than horse-drawn vehicles.

60. The principles to be observed and the methods to be employed in making the location of a wagon road are substantially the same as those used in the location of a railroad. The method of examining the country and of making surveys will not be considered here, as such subjects are elaborately presented in treatises on railroad location.

The fundamental principles applicable in locating a new rural road or in improving an old one will be briefly considered; but no hard and fast rules can be laid down, for each road must be designed for the place it is to occupy and the service it is to render. In the location of any road there will always be an opportunity to exercise keen insight and good judgment.

The subject will be considered under the five heads: distance, grades, curves, width, and placing the line.

61. DISTANCE. Other things being equal, the shorter the road the better, since any unnecessary length causes a constant threefold waste: (1) the interest on the cost of constructing the extra length; (2) the ever-recurring cost of repairing it, and (3) the time and labor employed in traveling over it. However, the advantage of straightness, i. e., of shortness, is usually greatly over-estimated. The difference in length between an absolutely straight line and one deflecting a little to one side is not very great. For example, in Fig. 3, if $A\ B = B\ C = 1{,}000$ feet, and $B\ D = 10$ feet, the line $A\ B\ C$ is only one tenth of a foot longer than the line $A\ D\ C$. If $A\ B = B\ C = 1$ mile, and $B\ D = 300$ feet, the line $A\ B\ C$ is only 17 feet longer than $A\ D\ C$. "If a road between two places ten miles apart were made to curve so that the eye could nowhere see more than a quarter

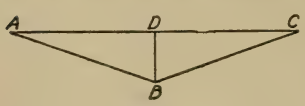


FIG. 3.

of a mile of it at once, its length would exceed that of a perfectly straight road between the same points by only about one hundred and fifty yards."

One of the most common defects of ordinary country roads is that distance has been saved by a disregard of the desirability of easy gradients. The curving road around a hill may often be no longer than the straight one over it. The latter is straight only with reference to the horizontal plane, but curved as to the vertical plane; while the former is curved as to the horizontal plane, but straight as to the vertical plane. Both lines curve, and the one passing over the hill is called straight only because its vertical curvature is less apparent to the eye.

62. Value of Saving Distance. Theoretically the value of a difference in length may be computed by determining (1) the amount of traffic, (2) the cost per ton-mile, and (3) the total coat of conducting the traffic; and then assuming that the value of any difference of length *is to* the total cost of transportation *as* the difference of the length *is to* the total length. If the annual cost of conducting transportation over a given road is known, then this cost divided by the length of the road gives the annual interest upon the sum that may be reasonably expended in shortening the road 1 mile, i. e., the value of a saving of a mile of distance; and of course dividing this sum by the number of feet in a mile will give the value of saving 1 foot of distance.

Unfortunately it is not possible to determine the amount of traffic with any considerable degree of accuracy. At some railroad stations the sole freight shipped out is agricultural produce, in which case the traffic over any particular wagon road can be approximated by distributing the shipments according to the contributing area. The average load can be determined with sufficient accuracy by consulting the records of the grain dealers. In addition to the above, which may be called the heavy freight traffic, there is a considerable amount of light freight and passenger traffic which would be benefited by a saving of distance.

For the sake of working out an example, it will be assumed that the cost of transportation is 10 cents per ton-mile. This cost is made up of the cost of loading and unloading, of driving, of feed, and of wear and tear of horses, wagon, and harness. The cost of loading and unloading is independent of distance. The cost of driving nominally varies as the time, i. e., as the distance (see third paragraph of § 63). The cost of wear and tear varies as the distance;

but the cost of feed does not so vary. It is impossible to assign reliable values to these several factors of the cost, but it is certain that only part of the cost of transportation varies as the distance; and for the sake of completing the illustration, it will be assumed that 8 cents per ton-mile varies as the distance. This sum multiplied by the number of tons passing over the road in a year will give the sum that may be spent annually to secure a saving of 1 mile of distance.

For example, a road leading to a certain village was originally laid out on the east and north sides of a quarter-section, but on account of low ground on the northeast corner another road was opened on the south and west sides. The quarter-section was one large field. How much expense would the traffic justify in order to secure a road diagonally through the quarter-section. The heavy freight traffic was approximately 3,000 loads of 1 ton each per annum. The annual value of saving 1 mile would then be 8 cents $\times$ 3,000 = \$240. The saving in distance by going through the quarter-section is 0.29 mile; and the annual value of saving this distance is \$240 $\times$ 0.29 = \$69.60. The diagonal road would occupy $2\frac{1}{3}$ acres less land than the longer one; and as the land rented for \$3 per acre, this adds \$3 $\times$ $2\frac{1}{3}$ = \$7 per annum to the value of the diagonal road. The annual saving from these two items is then \$69.60 + \$7.00 = \$76.60. This is the interest at 5 per cent on \$1,532, which sum, according to the above computations, could be borrowed, and used to secure this improvement, and the community be no worse off financially.

In addition, there would be some advantage to the light freight and passenger traffic by shortening the road, but it was difficult, if not impossible, to estimate this saving; and as the benefit per trip would probably be less than for the heavy freight traffic, it was neglected. There would be a slight saving in the cost of maintenance of the shorter road, as in this case the soil and drainage was as good on one line as on the other. Further, there would be some saving on the return trip by the shorter road. On the other hand, it is probable that the smaller number of acres required for the diagonal road would cost at least as much as for the road around the quarter-section, owing to the farmers' justifiable dislike for non-rectangular fields, and because the diagonal road would divide the quarter-section.

63. There are several matters that materially affect the reliability of the method of the above investigation. In the first place, the cost of transportation can not be known with any degree of reliability. The farmers concerned would stoutly contend that the

price assumed above is much too great; while freighters would claim that it was too low (§ 4–9).

In the second place, not all of the computed annual saving is available for making the improvement, since some of it should be set aside to form a sinking fund to be used ultimately in extinguishing the debt. It is not the part of wisdom to extend the debt very far into the future, since the conditions may materially change. For example, a new railroad may divert the traffic from this particular road, or improvements in the condition of the surface of the road may decrease the cost of transportation,—either of which would decrease the value of the proposed improvement. Of course, certain contingencies may increase the traffic and thereby add to the value of the improvement; but it is not wise to incur a definite debt for an equal and somewhat problematic saving. Road reformers sometimes overlook the fact that interest is a yearly charge and that the debt must finally be paid.

In the third place, the cost of transportation does not necessarily vary proportionally to the distance, as was assumed above. If the difference in distance is sufficient to make a difference of one trip per day, then the value of the saving in distance is tangible; but where the saving in length is insufficient for an additional trip, the value of the difference in distance depends upon the value, for other work, of the small portions of time of men and teams which may be saved by the shorter route,—a value which exists, but which is difficult to estimate.

Therefore any estimate as to the value of a saving of distance is necessarily only a rough approximation; and at best it should be used only as a guide to the judgment.

64. The problem to find the value of saving distance is very different for wagon roads than for railroads. In the case of railroads the cost of the various elements has been carefully investigated for many years, and the transportation is all conducted under a single management and by the same party that maintains the road surface; while in the case of wagon roads, a multitude of private parties conduct the transportation under various conditions, and the maintenance of the road is in the hands of public officials.

65. GRADE. A level road is most desirable; but as it can seldom be obtained, we must investigate the effect of grades upon the cost of constructing and operating the road, and also determine what is the steepest allowable grade.

The grade may be reduced (1) by going round the hill or by

zigzagging up the slope, or (2) by cutting down the hill. If the slope to be ascended is a long one, the first method must be employed; but if the grade is short, the second is usually the cheaper. Increasing the length adds to the cost of construction and of transportation, while cutting down the hill adds only to the cost of construction. The maintenance of the longer and flatter line may cost either more or less than the shorter and steeper one according to the circumstances of the case. In a broken or rough country, a proper adjustment of the grades is the most important part of the art and science of road building, and the better the road surface the more necessary is such an adjustment.

66. All grades are objectionable for two distinct reasons, viz.: because a grade increases the amount of power required to move a load up it, and because a grade may be so steep as to limit the amount of the load that can be moved over the road. The first applies to all grades whatever their rate or height; while the latter applies only to the steepest grade on the road, and in a measure is independent of its height and depends only on its rate. At present only the first objection to grades will be considered; and subsequently the second objection will be discussed (§ 74).

67. Ordinary Effect of Grade. Table 9, page 24, shows the load (in terms of the weight of the horse) which a horse with a pull equal to one tenth of its weight can draw up various grades on several road surfaces. To emphasize the effect of the grade upon the load, the same data are presented in a slightly different form in Table 10, page 25, which shows at a glance the load on any grade in terms of the load on the level. Tables 9 and 10 show that the better the condition of the road surface, i. e., the less the rolling resistance, the more objectionable a grade. For example, according to Table 10, on iron rails on a 3 per cent grade a horse can draw only 10 per cent as much as on a level; while on a water-bound macadam road on a 3 per cent grade it can draw 25 per cent as much as on a level.

A horse can occasionally and for a short time exert a pull equal to more than one tenth of its weight. If the grade is not too long, a horse can safely exert a force equal to one quarter of its weight, and in emergencies one half.

To move a load over an ordinary earth road requires a tractive force of 100 lb. per ton (see Table 8, page 21); and therefore a team of 1200-lb. horses exerting a force equal to one tenth of their weight can draw 2.4 tons on the level. The reserve power to take the load up the hill is $(0.25 - 0.10) \times 1200 \times 2 = 360$ pounds. The

total load to be carried up the grade is the wagon and its load *plus* the weight of the team, or 2.4 + (1200 × 2 ÷ 2000) = 3.6 tons. The grade resistance is 20 lb. per ton for each per cent of inclination (§ 23); and the grade resistance for this load on a 1 per cent grade is 3.6 × 20 = 72 lb. Therefore, the grade up which a pull of 360 lb. will take the 3.6 tons is 360 ÷ 72 = 5 per cent, which is the maximum permissible grade for an earth road in ordinary condition. The team could probably pull this load up 400 to 500 feet of such a grade.

By the same method of analysis, the load for the same team on a level, muddy earth road having a tractive resistance of 200 lb. per ton is 1.2 tons, and the maximum permissible grade is 7.5 per cent.

For a water-bound macadam road having a tractive resistance of 33 lb. per ton, the load on the level is 7.3 tons, and the permissible maximum grade is 2.2 per cent.

68. What load can the above team take up a 4 per cent maximum grade on a water-bound macadam road having a tractive resistance of 33 lb. per ton? The grade resistance is 20 × 4 = 80 lb. per ton; and the tractive resistance is 33 lb. per ton; therefore the total resistance is 80 + 33 = 113 lb. per ton. The maximum tractive power of the team is equal to one quarter of its weight, or 600 lb.; and the grade resistance for the weight of the team = 2400 ÷ 2000 × 80 = 96 lb.; therefore the net tractive power of the team is 600 − 96 = 504 lb. Then the weight of the wagon and the load which the team can draw up this grade is 504 ÷ 113 = 4.4 tons.

69. Rise and Fall. By rise and fall is meant the vertical height through which the load must be lifted in passing over the road in each direction. One foot of rise and fall is a foot of ascent with its corresponding foot of descent. In passing over a ridge 10 feet high standing in the middle of a level plain, there is only 10 feet of rise and fall; and not 10 feet of rise plus 10 feet of fall. If the road is level, Fig. 4, then an elevation or depression of, say, 1 foot produces

Fig. 4.

Fig. 5.

literally 1 foot of rise and a corresponding foot of fall; but if the road is on a steep grade, Fig. 5, an elevation of 1 foot above the grade line or of a like amount below the grade line, literally speaking, produces no rise and fall, because in either case it is a continuous

up grade. However, as far as operation is concerned, the two cases are exactly alike, and each has a foot of rise and fall.

Rise and fall is measured by the number of vertical feet of rise, as shown by the differences of elevation on the profile.

70. The introduction of rise and fall is a question either (1) between the increased cost of operation and the increased cost of construction required to fill up the hollow or to cut down the hill, or (2) between the cost of operation of the rise and fall and of the increased distance necessary to go around the obstruction.

The following example is often cited as showing the improvement that can be made in locating roads. "An old road in Anglesea rose and fell between its extremities, 24 miles apart, a total vertical amount of 3,540 feet; while a new road laid out by Telford between the same points, rose and fell only 2,257 feet; so that 1,283 feet of vertical height is now done away with, which every horse passing over the road had previously been obliged to ascend and descend with its load. The new road is, besides, more than two miles shorter. Such is one of the results of the labors of a skilful road maker." The road may have been economically re-located, but the citation fails to show whether the increased cost of construction to eliminate rise and fall was justified by the decreased cost of operation.

The following example from the same author, also frequently quoted, shows that rise and fall was eliminated by increasing the distance, although no attempt is made to show that the increased distance was more economical than the rise and fall thereby eliminated. "A plank road, laid out between Cazenovia and Chittenango, N. Y., is an excellent exemplification of the true principles of road making. Both these villages are situated on the Chittenango Creek, the former being 800 feet higher than the latter. The most level wagon road between these villages rises more than 1,200 feet in going from Chittenango to Cazenovia, and rises more than 400 feet in going from Cazenovia to Chittenango, in spite of this latter place being 800 feet lower. It thus adds one half to the ascent and labor going in one direction; and in the other direction it goes up hill one half the height, which should have been a continuous descent. The line of the plank road by following the creek (crossing it five times) ascends only the necessary 800 feet in one direction, and has no ascents in the other, with two or three trifling exceptions of a few feet in all, admitted in order to save expense. There is a nearly vertical fall in the creek of 140 feet. To overcome this, it was necessary to commence far below the falls, to climb up the steep

hillside, following up the sides of the lateral ravines until they were narrow enough to bridge, and then turning and following back the opposite sides till the main valley was again reached. The extreme rise is at the rate of 1 foot to the rod (1 in $16\frac{1}{2}$), and this only for short distances, and in only three instances, with a much less grade or a level intervening."

71. *Classes of Rise and Fall.* In discussing the effect of rise and fall upon the operation of a road, a distinction must be made between three classes of rise and fall, as follows:

Class A. Rise and fall on grades at a less slope than the angle of repose (the grade on which a vehicle by its own weight will maintain a uniform speed), and so situated as not to require any addition to the total power required to move a load over the road.

Class B. Rise and fall on grades so steep as to require either the holding back of the load by the team or the application of brakes.

Class C. Rise and fall on the maximum grade.

72. An example of the first class of rise and fall is shown in Fig. 6. The team is relieved on the down grade an amount exactly equal to the extra tax upon the up grade, and the only effect upon the team is that the effort is concentrated on the up grade instead of being uniformly distributed over the road; but as the slope is assumed to be equal to or less than the angle of repose, the maximum effort is equal to or less than twice the normal. If the grade line rises above the level instead of dipping below it, the case is not changed except that the rise is a little more unfavorable, since the team has no relief before the increase in effort is required. Therefore this class of rise and fall costs little or nothing.

FIG. 6.

In the preceding examples, a change of velocity would alter the power required at any particular instant; but in wagon-road traffic the speed is always small and consequently the effect of variations of speed are quite small, and may be entirely neglected. On railroads a variation of the velocity materially affects the cost of rise and fall.

If the grade is greater than the angle of repose, the team in descending must hold back the load, which is lost energy, or brakes must be applied, which tend to destroy the road; and in ascending, the demand upon the team is greater than twice the normal. Therefore in either case this class of rise and fall adds to the cost of operating the road.

If the grade is the maximum, it may be sufficient to limit the

amount of the load a team may draw over the more level portions of the road, and therefore greatly add to the cost of transportation. As a chain is no stronger than its weakest link, so a road is no better than its steepest grade.

73. *Cost of Rise and Fall.* What does it cost to develop the power required to haul a load up a grade less than the grade of repose? In other words, what is the cost of Class A rise and fall?

The cost of transportation consists chiefly of the cost of driving, of feed, and of the wear and tear on the team. Usually the cost of driving will be approximately half of the total cost of transportation; and as a team can draw a load up the grade of repose at practically the same speed, at least for short stretches, as upon the level, there will usually be no material increase in the cost of driving. Even though the team may travel slower because of the grade, the cost of the increased time can scarcely be computed because of the impossibility of determining the value of fractions of time for other purposes. The cost of wear and tear on the team and part of the cost of feed must vary approximately as the total power developed. Therefore the conclusion may be drawn that rise and fall belonging to Class A will not add appreciably to the cost of transportation. This conclusion is corroborated by the popular belief that a gently undulating road is less fatiguing to horses than one which is perfectly level. The argument in support of this belief is that alternations of ascents, descents, and levels call into play different muscles, allowing some to rest while others are exerted, and thus relieving each in turn. The argument is false, and probably originated in the prejudices of man in his quest for variety, rather than in the anatomy of the horse; but the above theory would not have gained its wide popularity if a gently undulating road were appreciably more fatiguing to a horse than a perfectly level one. A perfectly level road is the best for ease of transportation.

74. Limiting Effect of a Grade. If the grade is steeper or longer than that up which the team can draw the normal load by exerting twice the tractive power required on the level, i. e., if the rise and fall belongs to Class C, then the grade has the effect of limiting the load that can be drawn over the level portion of the road, and consequently increases the cost of transportation. The load which a team can draw up any grade can be approximately computed as in § 68. If the load that can be drawn up any particular grade is, for example, three fourths of the normal load on the level; then it will cost as much to haul three fourths of a load with this grade as a full load without

the grade. If the cost with a grade less than the maximum is 10 cents per ton-mile (§ 4–7 and § 12), then the cost with the maximum grade will be $10 \div \frac{3}{4} = 13\frac{1}{3}$ cents per ton-mile; and therefore for each ton going over the road, the maximum grade adds $3\frac{1}{3}$ cents per ton mile. In determining the amount of traffic, only full loads should be included; but notice that the full load varies with the speed. A ton may be a full load at 3 miles per hour, while half a ton may be a full load at 6 miles per hour.

Knowing the load on the maximum grade and also the cost per ton-mile for a level road or for a grade less than the maximum, the justifiable expenditure to reduce the maximum grade may be computed as follows: The difference in cost per ton-mile with and without the maximum grade may be determined as in the preceding paragraph; and this multiplied by the number of loads annually going over the road gives the sum that may be spent annually to reduce the maximum grade to the lesser value. This sum may be used to pay interest on the cost of cutting down the hill or of filling up the hollow.

The data are so uncertain that the result must be regarded only as a rough approximation; and yet it is worth while to make an investigation as above as a guide to the judgment.

75. Class B rise and fall is intermediate between Class A and Class C, and its cost is even more difficult to compute than that of Class C. The chief difficulty is in determining the relative cost of developing power on a level and up a grade. Only an estimate can be made, and the estimate will vary greatly with the point of view. For example, farmers usually have a surplus of power (horses) as far as transportation is concerned, and therefore they would consider a slight increase in the demand for power as a matter of small moment. Again, teamsters differ greatly as to what is a proper or economical load for a horse, and also as to the effect of a temporary over-load.

There are two methods of computing the cost of this class of rise and fall, neither of which is more than roughly approximate.

1. Assume that the cost of Class B rise and fall bears the same relation to that of Classes A and C, that the grade of B bears to that of A and C. Then if the grade for Class B is only a little greater than the angle of repose, the cost is only a trifle greater than that of Class A; and if the grade is nearly a maximum, then the cost of the rise and fall closely approximates that of Class C.

2. Assume that the energy developed on a grade over and above

that required on the grade of repose, costs the same per unit as that of an equal amount of energy developed on the level. For example, assume that the rise is 1 foot more than the angle of repose; and assume that the cost of drawing a load on a good water-bound macadam road is 5 cents per ton-mile (§ 5–6), and that the tractive power is 40 lb. per ton. Then, moving a ton 1 mile will develop $5{,}280 \times 40 = 211{,}200$ foot-pounds of energy, which will cost 5 cents. The cost of 1 foot-pound of energy, then, is $5 \div 211{,}200 = 0.000{,}023{,}7$ cents. Drawing a ton over a rise 1 foot high develops 2,000 foot-pounds, the cost of which is $0.000{,}023{,}7 \div 2 \times 2{,}000 = 0.023{,}7$ cents. In going up the above grade, the team must develop enough power to move the load up the grade of repose and in addition must develop enough to lift the load 1 foot vertically. Therefore the cost of the 1 foot of rise assumed above is 0.023,7 cents for each ton going over the road.

It was assumed above that the load is retarded in the descent by the application of brakes; but if the grade in question is situated in a flat country where brakes are not usually placed upon vehicles, the team must hold back on the descent an amount equal to the extra energy required on the ascent, and therefore the cost of the foot of rise and fall will be, almost or quite, doubled.

With data similar to the above, and with a knowledge of the amount of traffic, it is a simple arithmetical process to compute the sum that may be spent annually to eliminate one or more feet of rise and fall. Notice that in this case only the full loads should be considered (see the first paragraph of § 74). For example, assume that a water-bound macadam road has a traffic of 20 tons per day one way for 300 days of the year, or an annual traffic of $20 \times 300 = 6{,}000$ tons. The cost of a foot of rise and fall per ton of traffic is 0.023,7 cents, and the annual cost on this particular road is $0.000{,}237 \times 6{,}000 = \$1.42$. This is the amount which, according to the above investigation, can be spent annually to cut down the hill or to fill up the hollow sufficiently to eliminate 1 foot of rise and fall.

Similarly, for an earth road having a cost of 15 cents per ton-mile and a tractive power of 100 lb. per ton, 1 foot of rise costs 0.028,4 cents, and the foot of ascent assumed above will cost 0.028,4 cents for each ton going over the road. If this road has a traffic of 5 tons one way for 300 days of the year, the annual cost of the foot of rise and fall is $0.028{,}4 \times 5 \times 300 = 44.6$ cents, which is the sum that can be spent annually to eliminate the foot of rise and fall.

From the point of view of the last solution, it appears that the cost of Class A rise and fall increases with the steepness of the grade, that is, increases as the rate of the grade approaches the angle of repose. In all probability this is correct, but all the data involved are too uncertain to warrant any further discussion of the subject here. However, the engineer should bear such relations in mind in solving a particular problem.

76. Distance vs. Rise and Fall. In locating a road the question may arise between the relative desirability of introducing rise and fall and of increasing the length of the road. The problem then is to determine the relative value of distance and of rise and fall.

If the conclusion in § 73 is correct, that the cost of Class A rise and fall is not appreciable, then the distance should not be increased at all to eliminate Class A rise and fall.

77. For Class B rise and fall an approximate solution can be obtained by assuming that it costs the same to develop a certain amount of energy in overcoming Class B rise and fall as to develop a like amount of energy in moving a load on a level road. This assumption is probably reasonably correct.

For example, the tractive resistance of the best water-bound macadam road is 33 lb. per ton, and the work necessary to raise 1 ton through 1 foot of rise is 2,000 foot-pounds; therefore to develop 2,000 foot-pounds of work on a level water-bound macadam road, a ton must be moved $2{,}000 \div 33 = 60$ feet. Hence the cost of operating 60 feet of distance on this road may be considered as equivalent to 1 foot of rise and fall. Therefore to eliminate a foot of rise and fall of Class B, the length of the road may be increased 60 feet. Table 14 gives the corresponding distance for other road surfaces.*

78. Apparently writers on roads have not made a distinction between the several classes of rise and fall. Herschel says: † "To determine whether it is more advisable to go over than around a hill, all other considerations being equal, we have this rule: Call the difference between the distance around on a level and that over the hill d (the distance around being taken as the greater), and call h

* The above relations are for a load transported on wheels. It may be interesting to know the corresponding relations for pedestrians. The work (energy) required of a man in walking is practically independent of the nature of the road surface. A man makes progress in walking by allowing his body to fall through a small space and then raising it again preparatory to another fall. For an average man, the energy expended in walking 16 to 20 feet horizontally is sufficient to raise his body through 1 foot vertically. Therefore, for pedestrians 1 foot of rise and fall is equivalent to, say, 18 feet of horizontal distance.

† Clemens Herschel, Science of Road Making; Prize Essay of the State Board of Agriculture of Massachusetts, Boston, 1869, p. 207–63; revised edition, *Engineering News*, New York, 1890, p. 9.

TABLE 14

HORIZONTAL DISTANCE EQUIVALENT TO 1 FOOT OF CLASS B RISE AND FALL

Earth roads, muddy	(tractive resistance	200	lb. per ton)	10 feet
" ordinary	"	100	"	20 "
" dry and hard	"	80	"	25 "
Stone-block pavement, best	"	40	"	50 "
" " ordinary	"	80	"	25 "
Gravel, best	"	50	"	40 "
" ordinary	"	80	"	25 "
Water-bound macadam road, best	"	33	"	60 "
" " " ordinary	"	50	"	40 "
Brick on concrete	"	25	"	80 "
Sheet asphalt	"	20	"	100 "
Iron rails, clean	"	10	"	200 "

the height of the hill. Then in case of a first-class road, we go round when d is less than $16h$; and in case of a second-class road, we go round when d is less than $10h$." Although not specially so stated, the above rule was plainly intended for water-bound macadam roads.

The above rule (which has been frequently quoted) recognizes no distinction between the several classes of rise and fall. It makes the avoidance of a foot of rise in going over a small culvert or of a foot of fall in crossing an open ditch, equally as important as the elimination of a foot of rise and fall on the maximum grade. It is not possible to draw sharp lines between the several classes of rise and fall, but it is certain that there is a great difference in cost between a foot of rise and fall on a flat grade and the same quantity on the maximum or limiting grade. Notice that the above rule makes the horizontal distance equivalent to a foot of rise much less than that stated in Table 14.

79. Maximum Grade. The fixing of the proper maximum or ruling grade is the most important matter connected with the location of a road. To do this intelligently, the maximum grade must be considered both as an ascent and as a descent. Viewed as an ascent, the maximum or ruling grade chiefly concerns the draught of heavy loads; and viewed as a descent, it chiefly concerns the safety of rapid traveling. In both respects, the effect of the grade in limiting the load depends upon its rate, and is practically independent of its length.

80. *As an Ascent.* The load which a team can draw over any road is determined by the length and steepness of the maximum grade; or, in other words, the length and rate of the permissible

maximum grade depends upon the endurance of the team. The method of computing the load that a team can draw up any grade was explained in § 68, page 47. That investigation shows that the permissible maximum grade varies greatly with the conditions of the surface; and that the better the surface the less should be the ruling grade. In other words, unless the maximum grade is light, the amount that can be hauled on a water-bound macadam road does not differ greatly from that on an earth road.

A team could probably pull the maximum load up a stretch of the maximum grade 400 to 500 feet long; and if the maximum grade does not occur too often, it could probably pull the load up a stretch two or three times as long. On long maximum grades, it is wise to provide a little stretch of nearly level grade upon which to let the team rest. In the above computation, the team is assumed to have a reserve power equal to that exerted on the maximum grade; but the power required to start the load may be four or five times the normal tractive resistance, and hence a nearly level resting place is required, so that the team may readily start the load.

81. Many books on roads state that if the maximum grade is long, the slope should be flattened toward the summit to compensate for the decreased strength of the fatigued horses. This reasoning is incorrect and the remedy is impracticable. The argument is incorrect since it assumes that if the horse is to develop energy to lift the load up the incline, it should not work at a uniform rate. Universally the race horse goes fastest on the home stretch; and if it is urged to its utmost speed at first, it is sure to lose the race. The recommendation is impracticable, since the topography would rarely permit the flattening of the grade at the top without increased expense, and it would not be wise to incur extra cost for this purpose.

82. If the loads are much heavier in one direction than in the other, it is permissible to oppose the lighter traffic with the steeper ruling grade.

83. *As a Descent.* Viewed as a descent, the maximum grade concerns chiefly the safety of rapid travel. Many writers on roads claim that the descending grade should not exceed the angle of repose, i. e., should not exceed the inclination down which the vehicle will descend by its own weight. This limit is impracticable, since the angle of repose varies with the kind of vehicle, degree of lubrication, amount of load, size of wheels, etc. Besides,

this limitation is unnecessary, since the resistance of traction increases as the speed, and in going down it is only necessary to drive faster to prevent the vehicle from unduly crowding upon the team; but of course this remedy has its limitations. Further, the speed in descending may be checked by the application of the brake; but it should be remembered that the use of the brake is detrimental to the road surface, particularly on the maximum grade.

Grades twice as steep as the angle of repose are operated without inconvenience or danger. In Europe it is usually assumed that on a good water-bound macadam road, of which the angle of repose is about 2 or $2\frac{1}{2}$ per cent, a 5 per cent grade is the maximum that can be descended safely at a trot without brakes; and, if the stretch is long, 3 per cent is considered the maximum for safety. On mountain roads having a water-bound macadam surface, freight wagons descend 12 per cent grades by the use of brakes, but only with expert drivers.

84. Safety at Summit. The grade each side of the summit should be such that two automobiles approaching the summit should be able to see each other when at least 200 feet apart, which is practically equivalent to limiting the grade for 100 feet on each side of the summit to 5 per cent, or in other words to limiting the sum of the grade for 100 feet either side of the summit to 10 per cent. This is particularly important on a road having only a one-track improved surface.

Where a highway crosses a steam or electric railway on the same level, and where the highway has a steep grade as it approaches the crossing, there should be sufficient level road at the top of the grade, say 50 feet, to permit a wagon or an automobile, particularly the latter, to stand while the train passes. If this condition does not obtain, an automobilist is liable to kill his engine at the top of the grade just as he is starting to cross the track and just as a train is coming. Automobilists quite frequently encounter such dangerous crossings.

The crossing should be wide enough, say 18 feet, to permit two vehicles to meet upon the crossing.

85. Table 15, page 57, are the limits recommended by a special committee of the American Society of Civil Engineers.* They are presented here for convenience of reference and comparison.

* Proc. Amer. Soc. of C. E., Vol. 42 (1916), p. 1612.

TABLE 15

MAXIMUM PERMISSIBLE GRADE

Kind of Road Surface.	Grade.
Stone block with bituminous filler	15
Gravel	12
Brick with bituminous filler	12
Water-bound macadam	12
Stone block with portland-cement filler	9
Bituminous macadam	8
Bituminous concrete	8
Portland-cement concrete	8
Bituminous carpet	6
Brick with portland-cement filler	6
Sheet asphalt	5
Wook block	4

86. Minimum Grade. Considering only the cost of transportation, a perfectly level road is the best; but it costs less to maintain a road upon a slight grade than one perfectly level. All roads should be higher in the center than at the sides, so as to shed the rain to the side ditches, but on any road longitudinal ruts are liable to form and interfere with the surface drainage; and therefore if the road is perfectly level in its longitudinal direction, its surface can not be kept free from water without giving it so great an inclination transversely as to expose vehicles to the danger of overturning or skidding. On a perfectly level road, every rut will hold water, which will soak into the road and soften it whether it be earth or broken stone; whereas with even a slight longitudinal grade, every wheel track becomes a channel to carry off the water. It is a common observation that earth roads running up hill and down dale have surfaces better to travel upon than more level ones. This is largely due to the better longitudinal surface drainage.

The harder the road material the less the necessity for longitudinal drainage of the surface. An earth road surface is certain to wear into ruts, and hence is greatly benefited by having a longitudinal slope. Gravel and broken-stone roads are liable to wear into longitudinal ruts, and hence need longitudinal drainage. Water-bound macadam roads built with the hardest limestones or trap are not easily worn into ruts, and therefore the necessity for a longitudinal grade is less with this class of construction.

A longitudinal grade decreases the cost of maintenance, and the advisability of introducing a grade for such a purpose depends upon the relative cost of constructing it and upon the capitalized value

of the cost of maintaining it. With earth roads the expenditures for maintenance are ordinarily too slight to justify much expense in securing a longitudinal grade; but with high class broken-stone roads, which naturally have a heavy traffic, a considerable expense to secure a slight longitudinal grade is usually justifiable. Engineers whose experience has been largely upon railroads and canals are prone to spend money to secure an absolutely level road, where a slight grade could be secured at less expense. In filling up a hollow or cutting down a hill, the employment of a light longitudinal grade may decrease the cost of construction and also the cost of maintenance without increasing the cost of transportation (§ 71–73). The important principle to remember is that a slight longitudinal grade is an advantage; although over a long stretch of level country it may not be practicable to secure it.

The following is the minimum grade adopted by leading engineers for water-bound macadam roads: in England 1 in 80 or $1\frac{1}{4}$ per cent; in France, by the Corps des Ponts et Chaussées, 1 in 125 or 0.8 per cent; in the United States 1 in 200 or 0.5 per cent.

87. Curves. Theoretically the shortest radius of curvature allowable on roads depends upon the width of the road, and upon the maximum length of horse teams frequenting the road or upon the speed of the shorter teams. Since the length of a four-horse team and vehicle is about 50 feet, to permit such a team to keep upon a 12-foot roadway would require a radius of the inside of the curve of about 100 feet; on a 16-foot roadway a radius of about 75 feet would be required; and on an 18-foot roadway, a radius of about 66 feet. In France the minimum radius is as follows: on main and departmental roads of which the trackway is 20 to 22 feet wide, 165, and in extreme cases 100 feet; on principal country roads which are 20 feet wide, 50. In Saxony the minimum radius on principal roads is 82 feet, and on ordinary country roads it is 40 feet.

" On mountain roads with grades of 1 or 2 per cent, heavy teams require curves of 40 feet radius, and light ones 30 feet; and with grades of 3 or 4 per cent, heavy teams require 65 and light ones 50 feet." " In extreme cases on mountain roads four- and six-horse teams haul maximum loads over 16-foot roads having a radius at their outer edge of 30 feet." However, in this case the roads on the curves must be level, as the rear team is expected to do all of the pulling on the curve.

88. For safety of automobile travel, curves should be so flat that two automobiles in approaching will be able to see each other

when at least 200 feet apart; and where this is not feasible, a conspicuous sign should be placed. When the curve is located on a grade, the radius of the curve should be not less than 300 or 400 feet, even if the view is unobstructed.

At the corners or intersections of roads, the hedges, trees, etc., should be removed so that automobilists approaching the corner can have an unobstructed view of the side road for 200 or 300 feet.

89. 90° Curves. There are many 90° curves in highways, especially in that part of the country where the land was surveyed according to the U. S. public land system. If a pavement 15 feet wide is constructed in the middle of a 50-foot right-of-way, and if the improvement is to be kept within the right-of-way at the corner, the radius of the center line of the curve can be only 52.9 feet. But by purchasing a comparatively small area on the corner, the length of the radius can be greatly increased. Fig. 7 shows a solution of this problem.* "The piece of land *L K M N* contains only 0.055 acres, and often the saving in the decreased amount of paving will more than pay for the extra land. In addition the right-of-way is not contracted at the corner as it is by the shorter radius curve, so that the 17.5-foot margin between the inner edge of the pavement and the proper tyline is preserved for use as an earth road around the corner as well as on tangents."

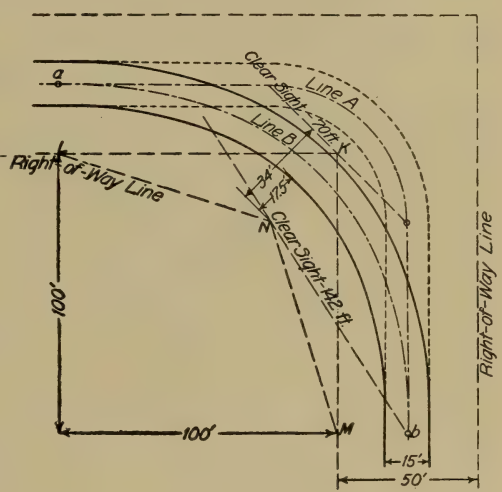


Fig. 7.—Curve of Paved Way at 90° Corner.

Fig. 8, page 60, shows the solution of the above problem at the intersection of two paved roads.† "Sections like *GHJKLPQR*

* H. E. Bilger, Road Engineer, Illinois Highway Department, *Illinois Highways*, January, 1917, p. 5.

† H. E. Bilger, Road Engineer, Illinois Highway Department, in *Engineering News-Record*, Vol. 79 (1917), p. 134.

should be built monolithic with the usual convexity of surface at JK, although J is depressed. Areas like HJK will come out warped surfaces, but are easily built by an experienced contractor. The

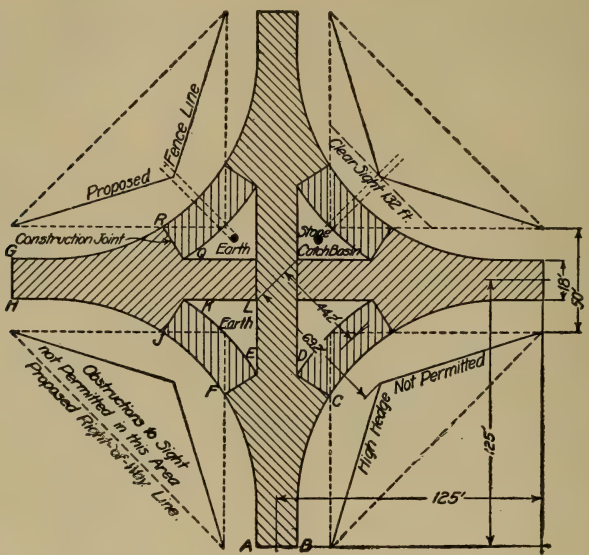


FIG. 8.—CURVES AT INTERSECTION OF TWO PAVED ROADS.

ten construction joints shown should be nothing more than planes of cleavage. Sections like $KEFJ$, which are built last, have their corner elevations fixed by the main pavement. Therefore the usual convexity of surface is preserved; and the inner edge FJ is depressed to meet the required elevation. In areas like KLE the surface of the ground should be kept about 1 inch below that of the surface of the pavement adjacent. The catch basins and drains will keep the ground dry."

90. Super-elevation. It is natural for vehicles to keep to the inside of the curve, partly to save distance and partly to get the benefit of the crown of the road to prevent tipping outward. If the curve has no super-elevation on the outside, the slew of the vehicle, particularly a fast-moving motor-driven one, will materially grind out the surface of the road.

The theoretically perfect super-elevation is given by the formula

$$E = \frac{W^2 S^2}{32.2\,R}, \quad \ldots\ldots\ldots \quad (1)$$

in which E is the elevation in feet, W the width of the road in feet, S the speed in miles per hour, R the radius of the curve in feet. However, the maximum super-elevation is limited by the transverse slope suitable for horse-drawn traffic.

The method adopted by the Illinois Highway Department is very simple and effective. It is as follows: "Whatever the character of the road surface, the inner half of the curve is carried around on the level; and the outer half of the curved roadway is elevated so that the surface is a right line from inside to outside on any radial line. For example, if the road surface is concrete 16 feet wide with a 2-inch crown, then the outer edge of the outer half will be elevated 2 inches, and the super-elevation of the curve proper will be 4 inches; and including the slope of the extra width (§ 97), the total super-elevation will be nearly 5 inches."

The California Highway Department employs the following method: The super-elevation on all curves is $\frac{3}{4}$ inch per foot, which on a 300-foot radius is perfect compensation for a speed of 17 miles per hour and on a 200-foot radius for 13 miles per hour.

When curves have the proper super-elevation, the tendency to keep to the inside of the curve will be less, and the damage due to slewing will be nearly or wholly eliminated. For the best results the super-elevation should begin a short distance before the tangent point and not reach its full amount until an equal distance past the tangent point.

91. Aesthetic Value of Curves. On a curved road there is a constantly changing panorama or vista before the traveler, rather than the constant and uninteresting vanishing point on a straight road. However, in most cases the location of buildings and the tillage of fields have fixed the location of the road within narrow limits; and hence there is but little opportunity to consider the aesthetic or artistic features of the location of the ordinary highway. In the location of park drives the artistic feature is the controlling element.

92. Width. Under this head will be considered the width of the right-of-way and also the width of the improved portion.

93. Width of Right-of-Way. The legal width of right-of-way varies greatly in different states. In an early day, before any attempt was made to improve the wheelway, the legal width was often 100 feet, and sometimes 10 rods (165 feet). In some of the states where land is cheap, the former width to some extent still prevails. In most of the states of the Mississippi Valley, particularly those in which the land was divided according to the system of U. S. public

land survey, the legal width of right-of-way is usually 66 feet. A few of these states classify the roads, making the less frequented ones narrower; for example, in Texas the widths of first, second, and third class roads are 60, 30, and 20 feet, respectively. In the earlier settled states along the Atlantic coast, 3 rods (49½ feet) is a common width, although some of the less frequented roads are only 2 rods (33 feet) wide.

If the surface is loam or clay, a considerable width of traveled way is required that the traffic may not cut the surface up so badly when it is soft. This is probably the explanation of the 60 or 66 feet so common in the Mississippi Valley. In some of the states, for example, Illinois, the law specifies that, "if possible," a strip equal in width to one tenth of the right-of-way shall be reserved for pedestrians on each side between the property line and the ditch. This leaves 53 feet for the wheelway and ditches, which is probably none too much for a loam or clay road. If the ditches are deep and consequently wide, the sidewalk is usually curtailed rather than the wheelway.

In Massachusetts the roads improved by state aid usually have a right-of-way of 50 feet wide, and in localities where there was a possibility of space being required by an electric road, they are 60 feet, the latter being considered sufficient to accommodate a double-track electric road, wagon ways, and sidewalks.

94. In England the principal roads, especially those near populous cities, are laid out 66 feet wide, 20 or 22 feet being covered with broken stone.

In Holland the usual width is 38 feet, of which 14 feet is improved.

In France the standard widths are to the nearest foot as follows:

Class of Road.	Right-of-Way.	Width Improved.
National roads	66 feet	22 feet
Departmental roads	40 "	20 "
Provincial "	33 "	20 "
Neighborhood "	26 "	16 "

95. Width of Improved Portion. In view of the cost of improving or paving the roadway, it is important to determine the proper or best width of the improved portion. The best or economic width of the improved portion depends upon (1) the cost of the paved portion, (2) the cost of constructing the shoulders, i. e., of partially improving or hardening the natural soil at the edges of the improved

portion, (3) the amount of travel, and (4) the proportion of motor-driven vehicles.

Except for cost, the wider the improved way the better; but length is more valuable than width, and it is often difficult to get an improved road because of the expense. Hence it is wise to make the paved way only wide enough to accommodate the travel reasonably well.

The width necessary for ordinary rural traffic is often overestimated. Two wagons having a width of wheel base of 5 feet and a width of load of 9 feet can pass on a 16-foot roadway and leave 6 inches between the outer wheel and the edge of the paved way and a clearance of 1 foot between the inner edges of the loads. This extreme case will rarely occur, and hence a width of 16 feet will certainly be enough unless there is considerable rapid traffic.

The Massachusetts Highway Commission carefully measured the width of traveled way on numerous crushed-stone roads, and found that with an improved width of 15 to 24 feet,—the average being 16.1 feet,—the maximum width of traveled way averaged 14.92 feet and the width commonly traveled averaged 11.05 feet.* On this evidence the Commission concludes that "a width of 15 feet is ample except in the vicinity of the larger towns, and that 12 feet is sufficient for the lighter traveled ways, but that 10 feet is too narrow unless good gravel can be obtained for the shoulders." The average width commonly traveled on forty-six of the 15-foot roads was 9.58 feet.

In New Jersey the improved width for state-aid roads is 9 to 16 feet, mostly 10 to 12 feet. The improved width of French roads varies from 16 to 22 feet (§ 94); in Austria, from 14 to 26 feet; and in Belgium there are many roads surfaced only $8\frac{1}{4}$ feet wide.

96. The preceding data for the width of the improved portion were fixed before automobiles became numerous. Naturally provision should be made to permit automobiles to pass safely at considerable speed; and hence the widths stated above are too small. Two automobiles can not safely pass at low speed upon less than 12 feet, and usually it is considered that a road having any considerable motor travel should have a width of 14 or 16 feet. The Massachusetts Highway Commission once built double-track roads 18 feet wide; but in consideration of the large number of wheels that went off the side of the improved way, increased the width to $19\frac{1}{2}$ feet, after which few, if any, wheels went off the side.

* Report of the Massachusetts Highway Commission for 1897, p. 31. For a summary of similar data for each township for five years, see Report for 1901, p. 47–55.

97. Width on Curves. If the deflection angle is more than about 30°, the traveled way should be widened on the curve. If there is likely to be much motor-driven traffic, the width at the center of the curve should be increased 30 to 40 per cent, the increase tapering to nothing at the tangent points.

The slope of the inner half of the curve should be continued over this extra width.

If the improved way is so narrow that a considerable number of vehicles turn off upon the shoulders, then the proper construction of the shoulders becomes a considerable item; and it may be wiser to improve a wider portion and spend less money upon the shoulders. Obviously the best width depends upon the amount of travel, the relative cost of the pavement and of improving the shoulders. It has been said that if a vehicle is compelled to turn off on the shoulder more than five times in going a mile, the improved portion should be widened.

Since earth roads have the same material in the shoulders as in the traveled way, and since the cost of an improved earth road is so small, the whole width between the side ditches should be improved. Since gravel roads are comparatively cheap to construct, and since there is only a little difference between the cost of the improved way and that of the shoulders, gravel roads can appropriately be wider than roads of higher unit cost. For current practice concerning the width of gravel roads, see Figs. 44 and 45, page 170. For examples of the way in which these principles have been applied in water-bound macadam, see Figs. 48–56, pages 197–99; and for concrete roads, see Fig. 75, page 243.

98. Location of the Wheelway. The improved portion is sometimes placed in the middle of the traveled way, and sometimes at one side. Apparently the natural position is in the middle with an earth track on each side; but in this case, if the pavement is crowned, as is usual, one half of the storm water falling on it is discharged upon the shoulder at each side of the pavement, i. e., upon that portion of the road the harder to keep in proper condition. On the other hand, if the improved portion is placed at one side of the traveled way, and if at the same time it is given a uniform slope toward the nearer side ditch, all of the storm water falling upon the improved portion will be discharged upon the unused shoulder next to the side ditch and therefore do no harm. Further, in many cases grass will grow upon the unused shoulder and protect it, so no harm will be done if an occasional wheel does turn off onto this shoulder.

The heavier loads usually go toward town; and therefore if the single-track improved portion is placed upon the right-hand side going toward town, the heavier loads will have the right-of-way (in the United States at least), and will not turn off from the paved portion.

99. CROSS SECTION. The cross section of a road or pavement depends upon the material of the road surface, and hence will be considered in the respective chapters following.

However, the data in Table 16 on the crown or transverse slope of the road surface are given here for convenience of reference and comparison. These values were recommended by a special committee of the American Society of Civil Engineers.*

TABLE 16

CROWN OF ROADWAY

MATERIAL OF ROADWAY.	TRANSVERSE SLOPE, Inches per Foot.	
	Maximum.	Minimum.
Earth	1	$\frac{1}{2}$
Gravel	1	$\frac{1}{2}$
Water-bound Macadam	$\frac{3}{4}$	$\frac{1}{2}$
Bituminous Macadam	$\frac{1}{2}$	$\frac{1}{4}$
Bituminous Concrete	$\frac{1}{2}$	$\frac{1}{4}$
Bituminous Carpet	$\frac{1}{2}$	$\frac{1}{4}$
Stone-block	$\frac{1}{2}$	$\frac{1}{4}$
Portland-Cement Concrete	$\frac{3}{8}$	$\frac{1}{4}$
Brick	$\frac{3}{8}$	$\frac{1}{4}$
Wood Block	$\frac{1}{4}$	$\frac{1}{8}$
Sheet Asphalt	$\frac{1}{4}$	$\frac{1}{8}$

100. PLACING THE LINE. The controlling points of a line are certain points at which the position of the road is restricted within narrow limits and is not subject to change. These may be points where the location is governed by the necessity of providing an outlet for the traffic, or points where the position of the line is restricted by topographical considerations—such as a summit over which the road must pass, or a suitable location for a bridge.

After the reconnoissance of the locality is completed and the

* Proc. Amer. Soc. of Civil Engr's, Vol. 42 (1916), p. 1615.

position and elevation of the controlling points are known, the line must be marked upon the ground. For example, assume that it is desired to run a road from *A* to *D*, Fig. 9, page 67, *D* being a pass over the ridge. If the road follows the line *A B C D*, it will have the profile shown near the bottom of Fig. 9. The average grade from *A* to *B* is 1 per cent, and from *B* to *C* 5 per cent. If it is desired to locate a road that shall have a grade no steeper than 5 per cent, we may begin at *D* and locate a line having an uniform 5 per cent grade. It is best to commence the location from *D*, since usually the slopes nearer the foot of the hills are flatter than those at the summit, and consequently there is more choice of position of the line there than at the summit. Frequently in rough country, the only controlling point fixed before beginning the location survey is the lowest pass over a ridge or mountain range.

Beginning at *D*, a line may be located either (1) by setting off the angle of the gradient on the vertical circle of a transit or on a gradienter, and sighting upon a rod which is moved until the line of sight strikes it at the same height from the ground that the instrument is above grade; or (2) the points for the line may be found by running a line of levels ahead of the transit, and measuring the distances by which to reckon the rate of the grade. The line *D E C*, Fig. 9, has a uniform gradient of 5 per cent.

If a contour map is at hand, the line can be located approximately by opening a pair of dividers until the distance between the points corresponds to 100 feet, setting one point on the place of beginning and the other on the next lower contour, which gives a line 100 feet long with a grade equal to the distance between contours—in Fig. 9, 5 feet.

The line *D F G* has a uniform grade of 5 per cent. From *H* to *A* the road will have considerably less grade than 5 per cent, and can have a comparatively wide range of position.

The average grade from *A* to *D* is a little less than 5 per cent, but the slopes are so steep between *D* and *C* that it is impossible, within the limits of the map, to locate such a line. If such a gradient is located from *D* toward *A*, it will necessarily make a number of short turns on itself, which, although undesirable, are sometimes unavoidable. These short turns seriously impede traffic, since vehicles can not easily pass each other on such short curves—particularly if each is drawn by a long team. Short turns are also dangerous in descending, in case control of the vehicle is lost or the team runs away.

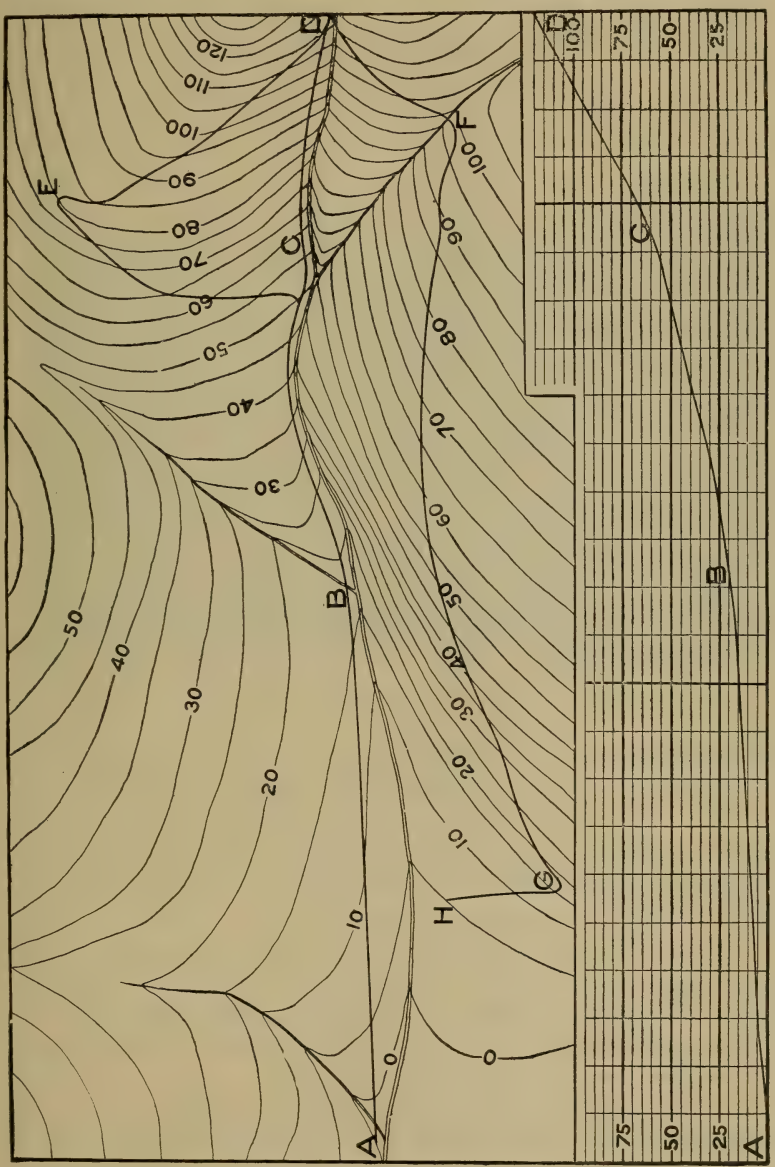


Fig. 9.—Road Location.

101. The line *A B C D* may be considered as an old road which it is proposed to improve by reducing the grades. Substituting the line *C E D* for *C D* changes the maximum grade from 10 to 5 per cent.

102. In placing the line attention should be given to the nature of the soil on alternative lines, since on one side of the valley the surface may be clay, upon the opposite gravel; in the bottom of the valley the soil is usually alluvial, while higher up it is generally better for road purposes. It should be remembered that in almost all steep slopes covered with loose material, the debris is either slowly moving down the slope or has attained a state of repose so delicately adjusted that an excavation for a road-bed on the inclined surface will again set the mass in motion. Such movements are particularly common in loose materials in countries where the frost penetrates deeply and the ground becomes very soft when thawing, and frequently entail long-continued and serious expense in maintenance.

If the road is to have a surface of gravel or broken stone, the relative proximity of the materials for the original construction as well as for repairs should be considered in deciding between possible locations. However, it should be remembered that after the road is completed, the amount of hauling required to supply materials for maintenance must of necessity be small in comparison with the ordinary traffic over the road; and hence this consideration should not have undue weight.

Attention should also be given to the disposal of the drainage water, and to the question of danger from high water in streams. For example, in Fig. 9 it is possible to locate a line on the upper side of the map with an uniform grade of 4 per cent, but such a line will lie so near the branch entering the main stream at *B* as to be in danger from floods. The matter of crossing streams should receive most careful study. Bridges are comparatively expensive to build and to maintain.

It may be cheaper to carry the road across the gully on an embankment or a trestle than to make a detour around the head of the valley. This question can be determined by comparing the greater cost of construction of the shorter line with the capitalized value of the greater cost of operating the longer line.

In some localities the protection of the road against snow is an important matter. Deep cuts almost always catch snow; and for this reason it is sometimes better to go around a point by a supported grade than to cut through it. In a snow country, roads should be located on slopes facing south and east in preference to slopes facing north and west, as the sun has greater power on the former to melt the snow.

"Nothing pays like first cost in road building," i. e., money expended in intelligent study of the location is the most economical expenditure in the construction of a road.

103. Example of Re-Location. Fig. 10 shows the old and the new location of a road. The old location, in the back-ground,

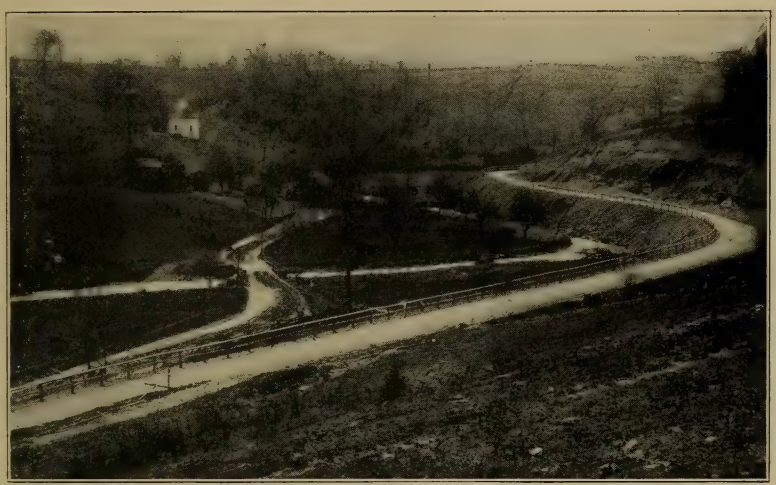


Fig. 10.—Re-Location of Road.

had many sharp curves, an undulating profile, and two stream crossings; while the new location has easy curves, no needless rise and fall, and no stream crossings.

104. Establishing the Grade Line. After placing the center line, the topography should be taken on each side of the line for some distance—the distance depending upon the lay of the land;—and then a map should be drawn showing the center line and the contours. This will serve to show whether the line is placed to the best advantage, and whether any changes are desirable. This is especially necessary over rough ground or where the line is on a maximum grade.

The center line for a final location should be carefully run and permanently marked, so that it may be re-located if necessary. A line of levels should be run and a profile drawn, upon which the grades may be established and from which the earthwork may be estimated (§ 138).

CHAPTER III

EARTH ROADS

106. In 1915 the surface of 87 per cent of the roads of the United States was the native earth (Table 12, page 33); and in all probability 70 to 80 per cent of these roads will always remain earth roads.

The earth road is the cheapest road in first cost. It is a light-traffic road, and only when the travel becomes considerable is it possible to procure the money with which to improve the surface by the use of some foreign material, as gravel or broken stone. Fortunately, the best form for the earth road is also the best preparation for any improved surface. This surface, whatever its nature, is only a roof to protect the earth from the effects of weather and travel, and any preparation that will enable the native soil when unprotected to resist these elements will enable it the better to serve as a foundation for the improved surface. Because of the importance of earth roads as a means of transportation and also because of the importance of a properly formed and well-drained road-bed for all improved road surfaces, earth roads will be considered somewhat fully.

107. The term earth road will be used as applying to roads whose surface consists of the native soil; and, unless otherwise stated, it will be understood as meaning a road whose surface is loam or clay.

Roads on loam and clay will be discussed in this chapter; and roads on sand or sand and clay mixed will be considered in the next chapter.

Art. 1. Construction

108. Width. The width of the right-of-way varies greatly but is usually between 40 and 66 feet (§ 93). With a 66-foot right-of-way it is customary to reserve about 6 feet outside of the ditch on each side for a foot-way, and to grade the remaining 54 feet. With a 40-foot right-of-way it is customary to reserve 6 feet on each side for a foot-way, thus leaving 28 feet for ditches and wheelways.

For equally good surface drainage, the greater width requires deeper ditches and more cost in construction; but permits a wider distribution of the travel which is an advantage when the roads are muddy or rough. The deep ditches are harder to maintain, and as a rule the native soil from the bottom of deep ditches is not so good for road building purposes as that nearer the surface. The cost of maintaining the road varies with the amount of travel, and is practically independent of the width. Therefore the width to be improved depends chiefly upon the width of the right-of-way, the character of the soil, the climate, and the first cost. In a wet climate, with soil easily working into mud, a wide wheelway is desirable; while in a dry climate, or with a soil not readily forming mud, a narrow wheelway is satisfactory.

109. Width on Curves. For a rule for widening the wheelway on curves, see § 97. This rule hardly applies to earth roads, but it is well to bear it in mind in locating or improving earth roads that may ultimately have a hard-surfaced wheelway.

110. Cross Section. The cross section or transverse contour of an earth road is an important matter with reference to the cost of construction and maintenance, and depends mainly upon the tools or machinery used in construction and maintenance and upon the form required for drainage. The subject is discussed fully in § 129–31.

111. Super-elevation on Curves. For a discussion of the super-elevation of the outer edge of the wheelway on curves, see § 90.

112. Grades. For a general discussion of the effect of both maximum and minimum grades upon the use and maintenance of a road, see § 79–86.

The principal problem in reference to grades is the determination of the maximum grade permissible. This problem does not admit of exact mathematical determination; and therefore recourse must be had to experience. For obvious reasons there are not many definite data under this head on record. In hilly country short grades of 1 in 3 (33%) are occasionally found—particularly in a newly settled country,—and grades of 1 in 4 (25%) are somewhat common. In a comparatively flat country, grades of 1 in 8 ($12\frac{1}{2}\%$) are not infrequent.

In improving the celebrated Holyhead road, Telford found in old roads many grades of 1 in 6 and 1 in 7. A number of roads improved by state aid in New Jersey originally had grades of 14 per cent. Of course only the roads having the most traffic were

improved; and probably less frequented roads in each locality have much greater grades.

For mountain roads, where the bulk of the traffic is usually down hill, the maximum grade is often 8 per cent and sometimes as much as 12 per cent. "Experience in heavy freighting has shown that wagons can be satisfactorily controlled in all weather on 12 per cent grades, but they can not be safely controlled on steeper grade."

113. DRAINAGE. Drainage is the most important matter to be considered in the construction of roads, since no road, whether earth or stone, can long remain good without it.

A perfectly drained road will have three systems of drainage, each of which must receive special attention if the best results are to be obtained. This is true whether the trackway be iron, broken stone, gravel, or earth, and it is emphatically true of earth. These three systems are underdrainage, side ditches, and surface drainage.

114. Underdrainage. Any soil in which the standing water in the ground comes at any season of the year within 3 feet of the surface will be benefited by drainage; that is, if the soil does not have a natural underdrainage, it will be improved for road purposes by artificial subsurface drainage. It is the universal observation that roads in low places which are thoroughly underdrained dry out sooner than undrained roads on high land. Underdrained roads never get as bad as do those not so drained. Underdrainage without grading is better than grading without drainage; and, in general, it may be said that where the soil does not have natural underdrainage, there is no way in which road taxes can be spent to better advantage than in subsurface drainage. Underdrainage is the very best preparation for a gravel or stone road. Gravel or broken stone placed upon an undrained foundation is almost sure to sink (perhaps slowly, but none the less surely), whatever its thickness; whereas a thinner layer upon a drained road-bed will give much better service.

115. *The Object.* The opinion is quite general that the sole object of underdrainage is to remove the surface water, but this is only a small part of the advantages of the underdrainage of roads. There are three distinct objects to be gained by the artificial underdrainage of a wagon road.

1. The most important object is to lower the water level in the soil. The action of the sun and the wind will finally dry the surface of the road; but if the foundation is wet, it will be soft and spongy,

the wheels will wear ruts, and the horses' feet will make depressions between the ruts. The first shower will fill these depressions with water, and the road will soon be a mass of mud. A good road can not be maintained without a good foundation, and an undrained soil is a poor foundation, while a dry subsoil can support almost any load.

2. A second object of underdrainage is to dry the ground quickly after a freeze. When the frost comes out of the ground in spring, the thawing is quite as much from the bottom as from the top. If the land is underdrained, the water when released by thawing from below will be immediately carried away. This is particularly important in road drainage, since the foundation will then remain solid and the road itself will not be cut up. Underdrainage will usually prevent the " bottom dropping out " when the frost goes out of the ground.

3. A third, and sometimes a very important, object of subdrainage is to remove what may be called the underflow. In some places where the ground is comparatively dry when it freezes in the fall, it will be very wet in the spring when the frost comes out—surprisingly so considering the dryness before freezing. The explanation is that after the ground freezes, water rises slowly in the soil by the hydrostatic pressure of water in higher places; and if it is not drawn off by underdrainage it saturates the subsoil and rises as the frost goes out, so that the ground which was comparatively dry when it froze is practically saturated when it thaws.

116. The underdrainage of a road not only removes the water, but prevents, or greatly reduces, the destructive effect of frost. The injurious effect of frost is caused entirely by the presence of water; and the more water there is in the road-bed the greater the injury to the road. The water expands on freezing, the surface of the road is upheaved, and the soil is made porous; when thawing takes place, the ground is left honeycombed and spongy, ready to settle and sink, and under traffic the road " breaks up." If the road is kept dry, it will not break up. Underdrainage can not prevent the surface of the road from becoming saturated with water during a rain, but it is the best means of removing surplus water, thus allowing the surface to dry and preventing the subsequent heaving by frost.

That frost is harmless where there is no moisture, is shown on a large scale in the semi-arid regions west of the Mississippi river. The ground there is normally so dry that during the winter, when

it is frozen, cracks half an inch or more wide form, owing to the drying and consequent contraction of the soil, which shows that there is no expansion by the freezing of water in the soil; and therefore in this region there is no heaving or disturbance by frost.

117. *The Tile.* The best and cheapest method of securing underdrainage is to lay a line of farm tile 3 or 4 feet deep on one or both sides of the roadway. The ordinary farm tile is entirely satisfactory for road drainage. It should be uniformly burned, straight, round in cross section, smooth inside, and have the ends cut off square. Tile may be had from 3 to 30 inches in diameter. The smaller sizes are usually a little over a foot long,—the excess length being designed to compensate for breakage; and the larger sizes are nominally 2 or $2\frac{1}{2}$ feet long, but usually a little longer. The cost of tile free on board at the factory is usually about as in Table 17, page 75. Y's for connections can be had at most factories, but they cost four or five times as much as an ordinary tile. With patience and a little experience ordinary tile can be cut to make fairly good connections.

Before the introduction of tile for agricultural drainage, it was customary to secure underdrainage by digging a trench and depositing in the bottom of it logs or bundles of brush, or a layer of stone; or a channel for the water was formed by setting a line of stones on each side of the trench and joining the two with a third line resting on these two. Apparently it is still the practice in some localities to use such substitutes for ordinary drain tile. Tiles are better, since they are more easily laid and are less liable to get clogged. Tiles are cheaper in first cost, even when shipped considerable distances by rail, than any substitute; and the drains are much more durable.

Tiles are laid simply with their ends in contact, care being taken to turn them until the ends fit reasonably close. In some localities there is apparently fear that the tile will become stopped by fine particles of soil entering at the joints, and consequently it is specified that the joints shall be covered with tarred paper or something of the sort; but in the Mississippi Valley, where immense quantities of tile have been laid, no such difficulty has been encountered. With a very slight fall or even no fall at all, tiles will keep clean, if a free outlet is provided, and they are not obstructed by roots of trees—particularly willow.

In some localities it is apparently customary to use collars around the ends of the tile to keep them in line. If the bottom of

the trench is made but little wider than the diameter of the tile, or if a groove is scooped out in the bottom of the trench to fit the tile, no difficulty need be apprehended from this source.

TABLE 17

COST AND WEIGHT OF DRAIN TILE

Inside Diameter.	Price per 1000 Ft. f.o.b. Factory.	Weight per Foot.	Number of Feet in a Car Load.
3 inches	$10.00	5 lb.	7 000
4 "	15.00	7 "	6 500
5 "	20.00	9 "	5 000
6 "	27.00	12 "	4 000
7 "	35.00	14 "	3 000
8 "	45.00	18 "	2 500
9 "	55.00	21 "	1 800
10 "	65.00	25 "	1 600
12 "	90.00	33 "	1 000
14 "	120.00	43 "	800
16 "	150.00	50 "	600
18 "	240.00	70 "	400
20 "	300.00	83 "	330
24 "	360.00	112 "	300

118. *The Fall.* There is no danger of the grade of the tile being too great, and the only problem is to secure sufficient fall. A number of authorities on farm drainage and also several engineering manuals assert that a fall of $2\frac{1}{2}$ or 3 inches per 100 feet is the lowest limit that should be attempted under the most favorable conditions; but practical experience has abundantly proved that a much smaller fall will give good drainage. In central Illinois and northern Indiana there are many lines of tile having falls of only $\frac{1}{6}$ to $\frac{1}{4}$ of an inch per 100 feet which are giving satisfactory drainage; and not infrequently ordinary tile laid absolutely level directly upon the earth in the bottom of the trench, without collars or other covering over the joints, has given fairly good drainage without trouble from the deposit of sediment. Of course, extremely flat grades are less desirable than steeper ones, since larger tile must be used, and greater care must be exercised in laying them, and since there is more risk of the drain's becoming obstructed; but these extremely flat grades are sometimes all that can be obtained, and even such drains abundantly justify the expense of their construction.

If possible at reasonable expense, the grade should be at least 2 inches per 100 feet; and unless absolutely necessary should never

be less than $\frac{1}{2}$ inch per 100 feet. On level or nearly level ground the fall may be increased by laying the tile at the upper end shallower than at the lower.

119. *Size of Tile.* The following formula has frequently been employed to determine the size of tile:

$$A = 1.9\sqrt{\frac{f}{l}d^5}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

in which A is the number of acres for which a tile having a diameter of d inches and a fall of f feet in a length of l feet will remove 1 inch in depth of water in 24 hours.

Equation (1) is based on the formula ordinarily employed for the flow of water through smooth cast iron pipe, and is only roughly applicable to tile. It probably gives too great a capacity for tile. However, all the factors of the problem are too uncertain to justify an attempt at mathematical accuracy. For example, we can not know with any certainty the maximum rate of rainfall, the duration of the maximum rate, the permeability of the soil, the amount of water retained by the soil, the effect of surface water flowing onto the road from higher ground, the area to be drained, etc. The above formula is useful only in a locality where there is no local experience with tile; and its chief value consists in showing the relation between capacity and grade, and the effect of a variation in the diameter of the tile.

The object of underdraining a road is to prevent the plane of saturation from rising so near the surface as to soften the foundation of the road even during a wet time, and therefore the provision for underdrainage should be liberal; but what will be adequate in any particular case depends upon the amount of traffic, the local topographic conditions, the character of the soil, etc. The best practice in agricultural drainage provides for the removal of 0.5 to 1 inch of water per day; but since the side ditches will assist in removing rain water from the road, it is probable that a provision for the removal of half an inch per day is sufficient for the underdrainage of a road. If there is an underflow of water from higher ground, or if the ground is "springy," then the ordinary provisions for underdrainage should be increased.

120. It is not wise to lay a smaller tile than a 4-inch one, and probably not smaller than a 5-inch. Tile can not be laid in exact line, and any tilting up of one end reduces the cross section. Again,

if there is a sag in the line equal to the inside diameter, the tile will shortly become entirely stopped by the deposit of silt in the depression.

It is sometimes wiser to lay a larger tile than to increase the fall. Ordinarily, the deeper the tile the better the drainage, although $3\frac{1}{2}$ or 4 feet deep is usually sufficient.

121. *Laying the Tile.* It is unwise to enter upon any detailed discussion of the art of laying tile. The individual tiles should be laid in line both vertically and horizontally, with as small joints at the end as practicable. Care should also be taken that the tile is laid to a true grade, particularly if the fall is small, for if there is a sag it will become filled with sediment, or if there is a crest silt will be deposited just above it. The drain should have a free and adequate outlet. The end of the line of tile should be protected by masonry, by plank nailed to posts, or by replacing three or four tiles at the lower end by an iron pipe or a wooden box.

122. *Cost of Laying Tile.* On the basis of 15 cents an hour for common labor, the prevailing cost of laying tile in loam with clay subsoil is about as follows: for 8-inch tile or less, 10 cents per rod for each foot of depth; for 9-inch, 11 cents; for 12-inch, 14 cents; for 15-inch, 17 cents; and for 16-inch, 18 cents. To aid in remembering the above data, notice that the price is 10 cents per rod per foot of depth for 8-inch tile or less, with an increase of 1 cent for each additional inch of diameter.

The cost of a mile of 5-inch tile drain is usually from $200 to $250, exclusive of freight on the tile. If there is any considerable amount of tiling, the above prices for the smaller tile can be reduced 10 to 20 per cent; and often there is enough discount on the prices given in Table 7, page 75, to cover the railroad freight-charges. A tile drain is a permanent improvement with no expense for maintenance, the benefit being immediate and certain; and therefore it is doubtful if money can be spent on earth roads to better advantage than in laying tile.

123. *One vs. Two Lines.* Usually a line of tile $2\frac{1}{2}$ to 3 feet deep under the ditch at one side of the road will give sufficient drainage. In case of doubt as to whether one or two lines of tile are needed, put in one and watch the results. If both sides of the road are equally good, another tile drain is not needed. In making these observations care should be taken not to overlook any of the contingent factors, as, for example, the difference in the effect of the sun upon the south and the north sides of the road, the effect of shade

or of seepage water, the transverse slopes of the surface of the road, etc.

124. *Location of Tile.* Some writers on roads recommend a line of tile under the middle of the traveled portion. With the same depth of digging, a tile under the side ditch is more effective than one under the center of the road. Further, if the tile is under the center, there is liability of the settling of the soil in the trench, which will make a depression and probably a mud hole; and if the tile becomes stopped, it is expensive to dig it up, and the doing so interferes with traffic. Finally, if the road is ever graveled or macadamized, the disadvantage of having the tile drain under the center of the road is materially increased.

Some writers advocate the use of a line of tile near the surface, on each side of the trackway. The object of placing the tile in this position is to secure a rapid drainage of the surface; but very little, if any, water from the surface will ever reach a tile so placed, since the road surface when wet is puddled by the traffic, which prevents the water's percolating through the soil. It is certain that in clay or loam the drainage thus obtained is of no practical value. Many farmers have tried to drain their barn-yards by laying tile near the surface, but always without appreciable effect. The deeper the tile the better the drainage.

The rapid surface drainage sought by putting a tile or its equivalent near the surface, can best be secured by giving the surface of the road a proper crown and keeping it free from ruts and holes (§ 205.)

While a line of tile on one side of the road is usually sufficient, there is often a great difference as to the side on which it should be laid. If one side of the road is higher than the other, the tile should be on the high side to intercept the ground water flowing down the slope under the surface. Sometimes a piece of road is wet because of a spring in the vicinity, or perhaps the road is muddy because of a stratum which brings the water to the road from higher ground; in either case, the source of supply should be tapped with a line of tile instead of trying to improve the road by piling up earth.

125. Side Ditches. The side ditches are to receive the water from the surface of the traveled way, and should carry it rapidly and entirely away from the roadside. They are useful, also, to intercept and carry off water that would otherwise flow from the side hills upon the road. Ordinarily they need not be deep; but, if possible, should have a broad, flaring side toward the traveled way,

to prevent accident if a vehicle should be crowded off the side of the roadway. The outside bank should be flat enough to prevent caving.

If the road is tiled as above recommended, the side ditch need not be very large; but it should be of such a form as to permit its construction with the road machine or scraping grader (§ 155) or with a drag scraper (§ 150), instead of by hand. On comparatively level ground, the proper form of side ditch is readily and cheaply made with the usual road machine. Fig. 11, page 82, shows a shallow ditch of the proper form; and Fig. 12 shows a deeper one of the same general form. If a larger ditch is needed, it should be of such a form as to be made chiefly with the drag-scoop scraper.

A deep narrow ditch is expensive to maintain, since it is easily obstructed by caving banks, by weeds, and by floating trash. Fortunately the shallow ditch is easy and cheap to construct and also to maintain. If it is necessary to carry water along the side of the road through a rise in the ground, it is much better to lay a line of tile and nearly fill the ditch than to attempt to maintain a narrow deep ditch. A tile is much more effective per unit of cross section than most open ditches.

126. The side ditch should have a uniform grade and a free outlet into some stream, so as to carry the water entirely away from the road. No good road can be obtained with side ditches that hold the water until it evaporates. For this reason much ostensible road work is a positive damage. Piling up the earth in the middle of the road is perhaps in itself well enough, but leaving undrained holes at the side probably more than counterbalances the benefits of the embankment. A road between long artificial ponds is always inferior and is often impassable. It is cheaper and better to make a lower embankment, and to drain thoroughly the holes at the side of the road. Public funds often can be more widely used in making ditches in adjoining private lands than in making ponds at the roadside in an attempt to improve the road by raising the surface. It is cheaper and better to allow the water to run away from the road than to try to lift the road out of the water.

When the road is in an excavation, great care should be taken that a ditch is provided on each side to carry away the water so that it shall not run down the middle of the road. Every road should have side ditches, even one that runs straight down the side of a hill. Indeed, although it often has none, the steepest road needs the side ditch most. Frequently the water runs down the middle of

the road on a side hill and wears it into gullies, which are a discomfort, and often dangerous, in both wet weather and dry.

In a slightly rolling country, the side ditch frequently has no outlet, and the water is allowed to accumulate at the foot of the slope and there remain until it is absorbed by the ground or seeps into the tile drain. The water seeps away very slowly because the fine silt carried down by the water fills up the pores of the native soil and renders it nearly impervious. The difficulty could be remedied by providing an inlet from the open ditch to the tile. This may be a well, walled with plank or masonry without mortar (except near the top) and having a grating in the side or top through which the water may pass. The well should be large enough to allow a man to enter it to clean it, and should extend a foot or more below the bottom of the tile. Earth roads in villages and towns are usually better provided with such inlets than country roads, but both could be materially improved at comparatively small expense by providing inlets from the side ditch into the tile.

127. If it can be prevented, no attempt should be made to carry water long distances in side ditches; for large bodies of water are hard to handle, and are liable to become very destructive. Side ditches should discharge frequently into the natural watercourses, though to compass this, it may in some cases be necessary to carry the water from the high side to the low side of the road. This is sometimes done by digging a gutter or by building a dam diagonally across the road, but both are very objectionable. A better way is to lay a tile or put in a culvert (Fig. 53, page 198), the amount of water determining which shall be done.

It is sometimes necessary to carry water a considerable distance in the side ditches, as, for eaxmple, when the road is in excavation. This requires deep ditches, which are undesirable and dangerous; and if the grade is considerable, the ditches wash rapidly. In such cases, it is wise to lay a line of tile under the side ditch, and at intervals turn the water from the surface ditch into the tile drain. This can be accomplished readily by inserting in the line of porous tile a Y section of vitrified pipe, with the short arm opening up hill. Of course, the short arm, i. e., the vertical arm, need not be as large as the body. If necessary, two or three lengths of porous tile may be added at the upper end of the Y to make connections with the bottom of the open ditch. Earth, sods, or stones, can be piled around the upper end of the tile to make a dam and to hold the tile in place.

Some road engineers lay a line of tile under the side ditch, and fill the trench with broken stone, thus making the tile carry both the surface water and the underdrainage. This practice probably affords better surface drainage, but it costs more than to allow the surface water to flow away in the side ditches. This construction is sometimes defended on the ground that the broken stone prevents the wheels from striking the tile when vehicles in passing are forced into the ditches. This danger does not seem very great, and would not occur at all if the tile were laid at the proper depth; but this is sometimes impossible owing to a hard substratum.

128. As a rule side ditches will not have too much fall; but sometimes a ditch straight down a hill will have so much as to wash rapidly, in which case it is an advantage to put in an obstruction of stone or brush. In extreme cases the bottom of the ditch is paved with stones.

129. Surface Drainage. The drainage of the surface of a road is very important, and is provided for by crowning the surface and keeping it smooth. It should be remembered that water upon the surface of the road can not be carried away by the underdrains, since the water can reach them only after it has penetrated and softened the road surface. The slope from the center to the side should be enough to carry the water freely and quickly to the side ditch; and if the surface is kept free from ruts and holes, less crown will suffice than if no attention is given to keeping the surface smooth. If there is not enough crown, the water can not easily reach the side ditches; and hence the road soon becomes watersoaked.

On the other hand, the crown may be too great. If the side slopes are so steep that traffic keeps continually in the middle, the road will be worn hollow and retain the water instead of shedding it promptly to the side ditches. If the crown is too great, it is difficult for vehicles to turn out in passing each other. Again, if the earth is piled too high in the middle, the side slopes will be washed into the side ditches, which not only damages the road but also fills up the ditches. Further, if the side slopes are steep, the top of the wheel will be further from the center of the road than the bottom; and the mud picked up by the bottom of the wheel will be carried to the top of the wheel and then dropped farther from the center of the road than it was before, each passing vehicle moving the earth from the center toward the side of the road. Finally with the ordinary method of caring for earth roads, more water stands on a very convex road than on a flatter one.

The slope from the center to the side should be at least half an inch to a foot, or 1 foot in 24 feet; and it should not be more than 1 inch to a foot, or 1 foot in 12 feet. If the surface is well cared for, the former is better than the latter; but in no case is it wise to exceed the latter slope.

Some claim that theoretically the cross section of the surface should be the arc of a circle, and others that it should consist of two planes meeting at the center and having their junction rounded off with a short curve. Great refinement in this matter is neither possible nor important. Two examples of a properly crowned road are shown in Figs. 11 and 12. The crown can be easily and cheaply constructed with the scraping grader (§ 155).

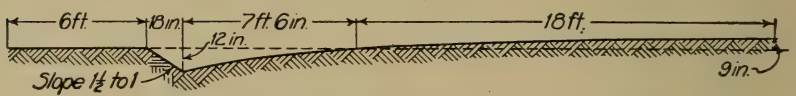


FIG. 11.—ROAD SURFACE AN ARC. SHALLOW SIDE DITCH.

The drainage of the surface of a road is chiefly a matter of maintenance (see Art. 2 of this chapter); and one of the most common defects of maintenance is the failure to fill ruts and keep the surface smooth so that the water will be promptly discharged into the side ditches. A comparatively shallow rut will nullify the effect of any

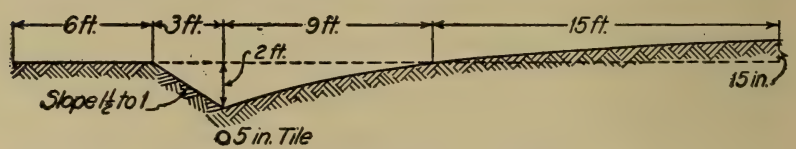


FIG. 12.—ROAD SURFACE AN ARC. DEEP SIDE DITCH.

reasonable amount of crown. Seldom is a mile of road seen which does not have a number of ruts and saucer-like depressions which catch and hold the water. On undulating roads, ruts and holes are naturally drained; and this is the reason why undulating roads are better than perfectly flat ones (see Minimum Grade, § 86).

Fig. 13 shows a form of cross section sometimes adopted for earth roads in villages and towns. The gutter usually is made next to the sidewalk, which is objectionable, since horses must stand in the mud and water when hitched in front of the abutting property. The form shown in Fig. 12 is free from this objection. A narrow berm is left between the sidewalk and the edge of the slope to prevent crowding the gutter too close to the shade trees, which are

usually planted just outside of the sidewalk. The gutter shown in Fig. 12 decreases the available wheelway, and consequently in some localities would be undesirable. This cross section also can be made and maintained with the ordinary scraping grader.

FIG. 13.—CROSS SECTION OF VILLAGE STREET.

130. The crown should be greater on steep grades than on the more level portions, since on the grade the line of steepest descent is not perpendicular to the length of the road, and consequently the water in getting from the center of the road to the side ditches travels obliquely down the road. If the water once commences to run down the center of the roadway on a steep grade, the wheel tracks are quickly deepened, and the road becomes rough and even dangerous. Under these circumstances, it is necessary to construct catch-waters ("water-breaks," "hummocks," or "thank-you-marms") at intervals to catch the water which runs longitudinally down the road, and to convey it to the side ditches. These catch-waters may be either broad shallow ditches or low flat-ridges constructed across the road; and they may slope toward one or both side ditches. In the former case, they should cross the road diagonally in a straight line; and in the latter case, in plan they should be a broad angle with the apex at the center of the road and pointing up hill. There is little or no difference between the merits of the ditch and the ridge, unless the bottom of the former is paved with gravel, broken stone, or cobbles. The ridges are more common, but usually are so narrow and so high as to form a serious obstruction to travel, a fact which is especially objectionable since the introduction of the automobile. However, neither the ditches nor the ridges should be used except on steep grades where really necessary, since either form is at best an obstruction to travel. The angle that the catch-waters shall have with the axis of the road should be governed by the steepness of the grade—the steeper the grade the more nearly should the catch-waters run down the road. They should have a considerable breadth so that wheels may easily ascend them and horses will not stumble over them.

Catch-waters should be constructed also in a depression where an ascending and a descending grade meet, in order that they may collect the water that runs down the traveled way and convey it

into the side ditches. These catch-waters should run square across the road, and should be quite shallow ditches, the bottom of which should be hardened with gravel, broken stone, or cobbles.

131. Some writers recommend that the surface of a road on the face of a hillside should consist of a single slope inclining inwards (see Fig. 14). This form of surface is advisable on sharp curves, but

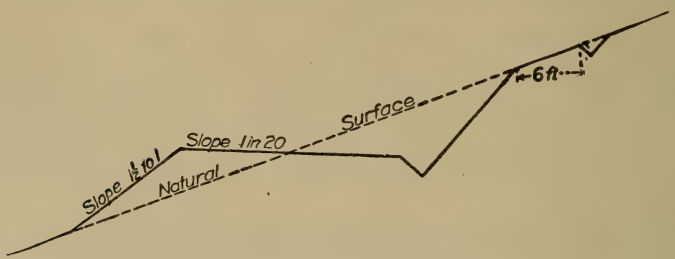


FIG. 14.—IMPROPER CROSS SECTION OF ROAD ON SIDE HILL.

is of doubtful propriety elsewhere. The only advantage of this form is that the water from the road is prevented from flowing down the outer face of the embankment; but the amount of rain water falling upon one half of the road can not have a very serious effect upon the side of the embankment. With a roadway raised in the center and the water draining off to either side, the drainage will be more effectual and speedy than if the drainage of the outer half must pass over the inner half. If the surface is formed of one plane, as in Fig. 14, the lower half of it will receive the greater share of the travel as the tendency is to keep away from the edge; and as this part of the surface will be more poorly drained, it is nearly certain to wear hollow. This will interfere with the surface drainage; and consequently a road with this section will require excessive attention to keep it in good condition. Figs. 53 and 54, page 198, show two forms of Swiss hillside roads having the center higher than either side.

Whatever the form of the road surface, if the hillside is steep there should be a catch-water above the road to prevent the water from the hillside above flowing down on the road. Fig. 14 shows such a catch-water. It should be, say, 6 feet back from the excavation, and should have a width and depth according to the amount of water to be intercepted.

132. EXCAVATION AND EMBANKMENT. Side Slopes. The angle of the slopes of the cuts and fills is designated by the ratio of the horizontal to the vertical distance. Thus, if the face of the fill

has an inclination of $1\frac{1}{2}$ feet horizontal to 1 foot vertical, the slope is designated as $1\frac{1}{2}$ to 1.

The slope of the excavations varies with the nature of the soil, being for economy as steep as the tenacity of the soil will permit. Solid rock may be cut with a slope of $\frac{1}{4}$ to 1. Common earth will stand 1 to 1, or $1\frac{1}{2}$ to 1—the latter being safer and more usual. Gravel requires $1\frac{1}{2}$ to 1. Some clays will stand 1 to 1, while some require a much flatter slope—in extrene cases 6 to 1. Fine sand requires a slope of 2 to 1, or 3 to 1.

The slope of embankment has less range than that of excavations, since there is less variety in the nature and the condition of the materials, and is usually $1\frac{1}{2}$ to 1.

133. In both railroad and wagon-road work, it is customary to establish all earthwork slopes as planes intersecting each other in right lines. The original form is never maintained, since it is not a form of equilibrium and stability. Storm water soon washes away the angle formed by the intersection of the two plane surfaces at the top of the embankment, and the water flowing down the slope soon rounds out the angle at the foot. Such construction violates one of the fundamental principles of stability, and it is a needless expense to build laboriously a form of construction which nature will inevitably destroy.

The transverse contours of the embankment and excavation shown in Figs. 15 and 16 are designed to meet the above objections

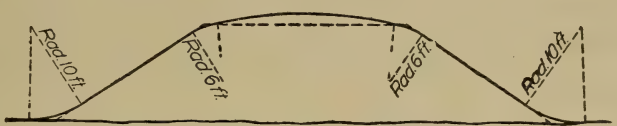


FIG. 15.—CROSS SECTION FOR EMBANKMENT.

to the ordinary forms of construction. These sections are designed in accordance with the forms of railroad excavations and

FIG. 16.—CROSS SECTION FOR EXCAVATION.

embankments recommended by D. J. Whittemore, the distinguished chief engineer of the Chicago, Milwaukee and St. Paul Railroad,

whose forms have met with the unanimous approval of leading engineers.

It is customary in railroad construction to make the top of the earth embankment wider than the base of the gravel or broken-stone ballast, which gives a berm between the base of the ballast and the outer edge of the earth embankment. This berm has been omitted in Figs. 15 and 16, since with an earth surface there is nothing corresponding to the ballast.

134. If the natural slope above the cut is long or steep, a catch-water drain should be constructed along the upper edge of the excavation slope to prevent the surface water from above washing down over the face of the cut; but the catch-water should be well back from the edge of the excavation, to prevent the water in the drain from softening the upper angle of the slope (Fig. 14, page 84).

The slopes of both excavations and embankments should be sowed with grass seed. Sometimes the material of the embankment is such that grass seed will not grow, in which case it may be necessary to lay sod; but of course this is very expensive. The roots of the grass will hold the earth from slipping, and prevent the face of the slope from being gullied out and washed down.

135. There is a tendency for workmen in order to decrease the amount of labor required to leave the side slopes of embankments hollow and those of excavations rounding. When inspecting the work, this tendency should be borne in mind.

136. Setting Slope Stakes. For instructions as to methods of staking out the ground preparatory to beginning the work of excavating and embanking, see any of the standard volumes on railroad engineering.

137. Computing Earthwork. For the methods employed in computing the contents of excavations and embankments, see any of the various treatises on that subject; or for a briefer presentation of the subject, see books on surveying or railroad engineering.

138. Balancing Cuts and Fills. Other things being equal, the most economical position of the grade line is that which makes the amount of cuts and fills equal to each other. If the cuts are the greater, the earth therefrom must be wasted, i. e., deposited in spoil banks; and if the fills are the greater, the difference must be obtained from borrow pits,—both of which operations involve additional expense for labor and land. Sometimes it is more economical to make an embankment from near-by borrow pits than to bring the necessary material from a far-distant cut; or, vice versa, it is

sometimes more economical to waste the material from a cut than to send it to a remote fill. The most economical use of the material depends upon the machinery used in moving the earth, the character of the earth in both cuts and fills, the road over which the earth must be transported, the cost of haul, the price of land, the liability of cuts being filled with snow, etc.; and the matter must be decided by the engineer to the best of his judgment in each particular case.

When the road lies along the side of a hill, one side of the road is usually in cut and the other in fill; and it is customary so to place the center line that these two parts are at least nearly equal. However, where the side slopes are steep, it is better to make the road mostly in cuts on account of the difficulty of forming stable fills on steep slopes.

139. In railroad work it is the custom to balance cuts and fills on the longitudinal profile of the road, but in wagon-road work the fills as shown by the profile of the center line should be slightly in excess, to provide a place for the earth taken from the side ditches. On account of the expense, wagon roads follow the surface more nearly than railroads; and consequently the earth from the ditches is proportionally more in wagon-road construction than in railroad construction.

140. Shrinkage of Earthwork. With the ordinary soil, the act of excavation so breaks it up that it occupies more space after excavation than before; but when the material has been placed in an embankment it will usually occupy less space than in its original position. The expansion due to excavation is usually 8 to 12 per cent of the volume, and in extreme cases may be 40 per cent; but in placing the material in the embankment, it is compacted by the weight of the embankment itself, by the pounding of the hoofs and by the action of the wheels, until usually the final volume is less than the original.

At first thought it seems strange that earth should occupy less space when placed in an embankment than when in its original position, seeing that it is not so hard and firm, and that it will usually settle still farther after the embankment is completed. The following facts account for this phenomenon: 1. The continued action of frost has made the soil in its natural position more or less porous. 2. Earths which have been lying *in situ* for centuries become more or less porous through the slow solution of their soluble constituents by percolating water. 3. The surface soil is rendered

more or less porous by the penetration of vegetable roots which subsequently decay. 4. There is ordinarily more or less soil lost or wasted in transporting it from the excavation to the embankment.

The amount of shrinkage depends chiefly upon the character of the material and the means by which it is put into the embankment, and somewhat upon the moisture of the soil, the rainfall conditions while the work is in progress and soon afterwards, and the depth to which frost usually penetrates. If the soil is moist when placed in the bank, it will become more compact than if it is dry. Rain greatly affects the shrinkage, and embankments put up during a rainy season will be more compact than those built during a dry time. Soil from above the usual frost line is more porous than that not subject to the heaving effect of alternating freezing and thawing, and consequently shrinks more when put into an embankment.

The natural shrinkage of the ordinary soils is in the following order: (1) sand and sandy gravel least, (2) clay and clayey soil intermediate, and (3) loams most. The shrinkage according to the method of handling is in the following order, beginning with the least: (1) drag scrapers, (2) wheel scrapers, (3) wagons, (4) cars, (5) wheelbarrows. The usual allowance for shrinkage for drag-scraper work is as follows: gravel 8 per cent, gravel and sand 9 per cent, clay and clayey earth 10 per cent, loam and light sandy earth 12 per cent, loose vegetable surface-soil 15 per cent. The above results are for ordinary earth, and do not apply to such unusual materials as "buckshot," gumbo, very fibrous soil, etc., which have a much greater shrinkage. Solid rock will *expand* 40 to 50 per cent.

The shrinkage of earth should be considered in locating the grade lines to balance the cuts and fills.

141. Settlement of Embankments. The shrinkage of earthwork referred to above takes place chiefly during construction, but the continued action of the weight of the embankment and the effect of rain and traffic will usually cause a comparatively small settlement after completion. Sand or gravel embankments built with wheel scrapers will usually settle 1 to 2 per cent after completion, and clay or loam embankments about 2 to 3 per cent. With drag scrapers the settlement will usually be a little less than the above; and with dump carts or wagons, a little more. With wheelbarrows the settlement is usually about 10 per cent, but may be as much as 25 per cent, depending upon the moisture in the soil, the

rain during construction, and the length of time under construction.

The settlement of the embankment after completion should be taken into account when determining whether the bank has been raised to the proper height. The embankment should be built to such a height that after it has ceased to settle it will be at grade. The length of time required for this settlement depends upon the weather conditions. The proper adjustment of the height of the embankments to compensate for future settlement is an important matter with broken-stone roads and with pavements.

142. The above remarks about settlement do not apply to embankments built with the elevating grader (§ 161). The settlement of earth roads put up by these machines is of no importance, and depends upon the amount of rolling they receive.

143. Rolling the Embankment. Many writers on roads recommend the rolling of all new earth embankments. In view of the usual settlement of banks built with drag or wheel scrapers, it does not appear that rolling with a farm roller would be very effective, and a heavier roller is seldom available. Simply rolling the top of the finished bank is not worth much, since the effect of the roller does not reach very deep; and, besides, no roller will compact loose earth so that wheels and hoofs will not make depressions in it.* Further, it is not practicable to roll the bank during the progress of construction, except when the scraping and elevating graders are used. Finally, those who travel the road most are generally the ones who pay for the construction, and almost universally they prefer to compact the earth by traffic.

It is customary to roll the foundation of pavements, but the chief object of so doing is to discover soft places rather than to consolidate the surface; and, besides, the foundation of a pavement is protected from rain and the action of wheels, and therefore the effect of the rolling is permanent, while with an earth road it is not.

144. Over-haul. When earthwork is done by contract, the bid includes the cost of removing excavated material and depositing it in embankments, provided the necessary length of haul does not exceed a specified limit. When the material must be carried beyond this limit the extra distance is paid for at stipulated price per cubic yard per 100 feet of haul. This extra distance is known by the name of "over-haul" or simply "haul." For an explanation

* The heaviest steam rollers give a pressure of about 600 pounds per linear inch, while wagons frequently give twice, and occasionally three times, as much.

of the method of computing "haul," see treatises on earthwork or books on railroad surveying.

The specified limit, i. e., the distance of free haul, depends upon the conditions. It is sometimes made as low as 100 feet, and is sometimes 2,000 feet—the latter usually only in street work. In railroad work 500 feet is a common limit.

145. Frequently all allowances for over-haul are disregarded. The profiles, estimates of quantities, and the required disposal of material are shown to bidding contractors; and they must then make their own allowances, and bid accordingly. This method has the advantage of avoiding possible disputes as to the amount of the over-haul allowance, and on this account is adopted by some railroads.

146. Stability of Embankments. The principles to be observed in the formation of an embankment depend somewhat upon the machinery employed in doing the work, but a few general considerations are not out of place here.

Specifications usually require that "all matter of vegetable nature must be carefully excluded from the embankment." It is impracticable to do this when the road passes through grass land—particularly if the grade is built with a scraping grader (§ 155). It is desirable to remove brush, tall grass, and high weeds from the space to be occupied by the embankment and the borrow pit; but small twigs, leaves, and sod are no material detriment, and their removal is a needless expense—except at the point where the road passes from cut to fill. It is essential that all vegetable matter and loose porous soil should be removed at this point, otherwise there will be a soft place which will soak up water and make a mud hole and also weaken the bank just below it. When an embankment is to be made across a swamp, bog, or marsh, the site should first be drained as thoroughly as possible.

Perfect solidity should be the aim, and all necessary precautions should be taken to prevent or lessen the tendency of the bank to slip. To secure stability, embankments should be built in successive layers not more than 3 or 4 feet thick, and the vehicles conveying the materials should be required to pass over the bank, so as to consolidate the earth. Specifications sometimes state that the layers shall be made concave, but this refinement is scarcely ever necessary, although it is well to see that the layers are never very much convex. Embankments are sometimes first built up in the center, and afterwards widened by tipping or dumping earth over the side; but this never should be allowed.

When embankments are to be formed on sloping ground, it may be necessary to plow the ground or to cut steps in a rocky surface to keep the filling from sliding down the natural surface. In many cases where roads are to be constructed along steep slopes, it is found cheaper to use retaining walls (§ 192) to sustain the road upon the lower side and the earth-cut on the upper side than to cut long slopes or form high embankments.

147. Improving Old Roads. Country roads may be improved in any of several ways:

1. By changing the location, to secure better alignment or lower gradients. The method of doing this has been discussed in Art. 2, Chapter I.

2. By cutting down the hills and filling up the hollows, to secure easier gradients. A hill may be cut down without seriously interfering with traffic by cutting one side of the roadway down a foot or two with drag or wheel scrapers (§ 154), and then turning traffic on this portion and lowering the other side, continuing to cut down each side alternately until the desired depth is reached. If the earth is deposited upon the embankment in the hollow, the traffic will consolidate the road as it is built up, which is very desirable.

3. By laying tile and cutting open ditches, to improve the drainage, as has been discussed in § 114–28.

4. By re-forming the surface by the use of the scraping grader to improve surface drainage, as discussed in § 155–58.

5. By adding sand or gravel to a clay road, or clay to a sand road, to improve the surface, as considered in Chapter IV.

148. Road-building Machinery. In recent years there has been a great advance in the machinery employed in building earth-roads. The wheelbarrow was formerly much used for short hauls, but has been superseded by some form of drag scraper (§ 150) drawn by horses, and is never used now except for very small jobs, or in wet and swampy places. Formerly an embankment was constructed with plows and drag-scoop scrapers (Fig. 17, page 92), while now it is built much more cheaply and better with either the scraping grader (Fig. 23, page 96), or with the elevating grader (Fig. 28, page 101). Years ago earth was thrown into wagons or carts by hand and hauled to its destination, while now it is moved with the two- or four-wheel scrapers (Fig. 21 or 22, page 95). Earth was formerly moved considerable distances with the drag scraper, while now the wheel scraper is employed. Formerly the surface of the excavation was finished with the drag-scoop scraper, while now it is done much

better and more cheaply with the tongue scraper (Fig. 18, page 93) or the scraping grader (Fig. 23, page 96).

There are a variety of plows, dump carts, wagons, etc., used in moving earth, which need not be considered here. The dump cart is much in favor in the New England States, but is never used in the Mississippi Valley. The steam shovel and dump cars afford the most economical method of handling earth when the amount to be moved justifies the outlay for the plant; but as that would seldom be the case in highway work, this method will not be considered.

149. Scrapers. Scrapers are generally used to move material after it has been loosened by plowing. There are two principal kinds—the drag and the wheel scraper.

150. *Drag Scrapers.* There are three forms of the drag scraper —the scoop (Fig. 17), the pole-scraper (Fig. 18, page 93), and the Fresno scraper (Fig. 19, page 93).

151. The drag-scoop scraper, Fig. 17, is sometimes referred to as the drag scraper or simply the drag, and also as the slip scraper or the slip. It is made in three sizes. The smallest, for one horse, has a capacity of 3 cubic feet; and the two larger sizes, for two horses, have a capacity of 5 and 7 feet respectively. Some have metal runners on the bottom and others have practically a double bottom, both of which devices decrease draft and increase durability.

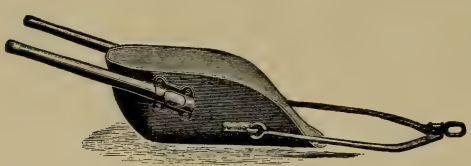


FIG. 17.—DRAG-SCOOP SCRAPER.

The drag-scoop or slip scraper is much used for moving earth short distances; but with it there is difficulty in building a bank of uniform solidity, since each scraperful is deposited in a compact mass by itself, with low loose places between them. Nor is the slip scraper suitable for finishing an embankment, since the surface made with it is a succession of humps and hollows which is very trying to drive over when dry, and when it rains the low places fill with water which speedily softens the remainder of the road, and finally produces mud holes. The pole or tongue scraper (§ 152) is much preferable for finishing the surface.

The drag-scoop or slip scraper is sometimes employed in loading wagons. This is done by building an elevated platform under which the wagons are driven, and to the top of which the earth is drawn in a scoop scraper upon an inclined runway. In the middle of the plat-

form is a hole through which the scraper is dumped. This arrangement of platform and runways is called a trap.

152. The pole or tongue scraper, Fig. 18, is ordinarily used for leveling up the road surface in excavations, and is frequently

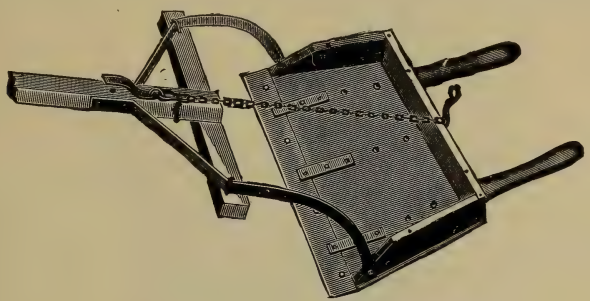


FIG. 18.—POLE OR TONGUE SCRAPER.

employed in preparing the subgrade for pavements. It may be used to transport earth short distances, but is not so good for this purpose as the scoop scraper. It is made in two sizes, 36 and 48 inches wide.

153. The Fresno scraper, Figs. 19 and 20 is the outgrowth of

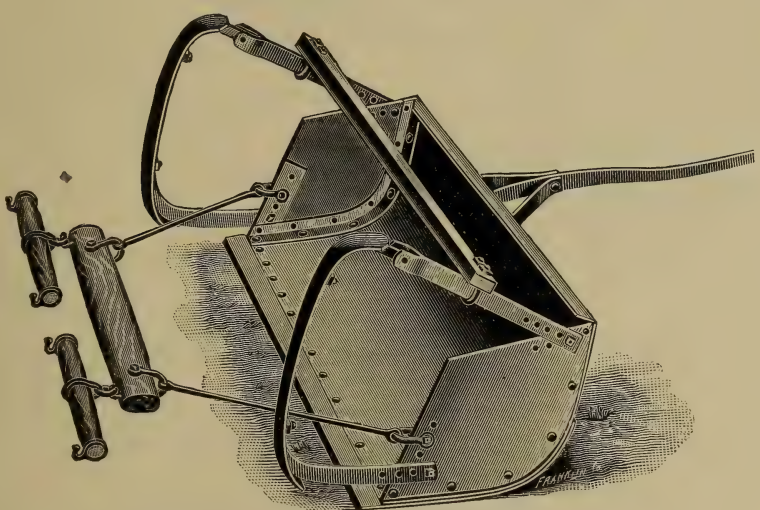


FIG. 19.—FRESNO SCRAPER, READY FOR LOADING.

experience in irrigation, and has some advantages over the common scoop scraper. (1) The proportions are such that it is more readily loaded to its full capacity. (2) It distributes the earth on

the bank better, as it can be adjusted to deliver in layers from 1 to 12 inches thick. (3) The runners make it more durable. (4) It is more easily loaded. (5) It will follow up a steep bank without dumping, and hence runways are not required.

Fresno scrapers are made in three sizes, the cutting edge being

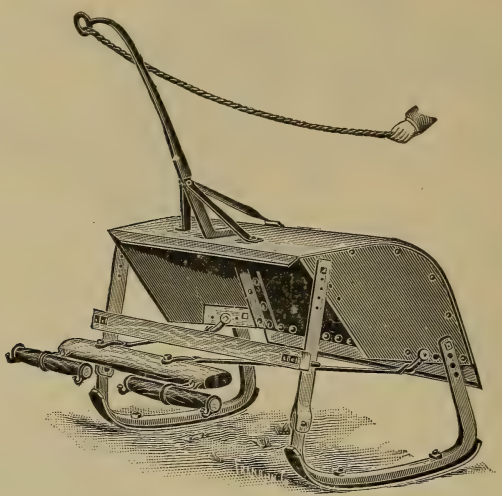


FIG. 20.—FRESNO SCRAPER, DUMPED

$3\frac{1}{2}$ feet, 4 feet, and 5 feet; and their respective capacity is 8, 10, and 12 cubic feet.

Under favorable conditions this form of scraper will push considerable earth along in front of it, and consequently the capacity is frequently stated as much greater than that given above.

154. Wheel Scrapers. There are two forms of wheel scrapers,—those with two wheels and those with four. The two-wheel scraper consists of a steel box mounted on wheels and furnished with levers for raising, lowering, and dumping, Fig. 21, page 95. It is made in three sizes, No. 1, 2, and 3, having a capacity of 9, 12, and 16 cubic feet, respectively. Some manufacturers make an automatic front end-gate which adds materially to the load the scraper will carry, particularly on a rough down-hill road.

The four-wheel scraper is a steel box or scoop suspended from a frame supported upon four wheels, see Fig. 22, page 95. It is made in two sizes, a half-yard and a yard capacity. It may be loaded by a snatch team or by steam power,—either a traction or a hoisting engine. The larger size is loaded with a 20 H.P. steam traction

engine or a 30–60 H.P. gasoline tractor, or by a hoisting engine; but when loaded, it is drawn by a two-horse team. The pan

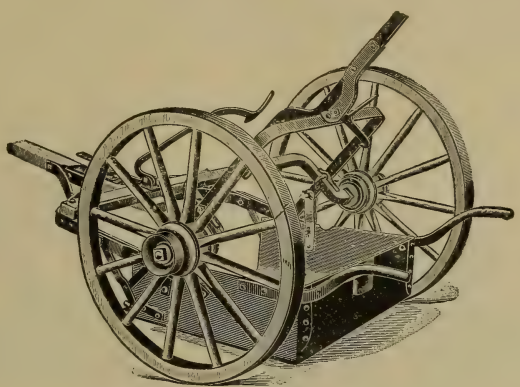


FIG. 21.—TWO-WHEEL SCRAPER, FILLING.

is raised and lowered by the tractive power. Work can be done cheaper with the four-wheel scraper than with the two-wheel scraper, because the former carries larger loads and also because it is self-loading and self-dumping. The four-wheel scraper has been called a self-loading and self-dumping wagon.

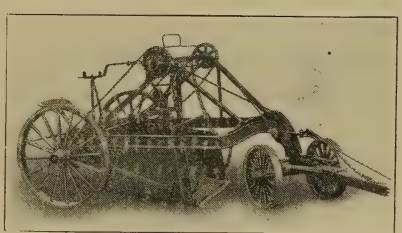


FIG. 22.—FOUR-WHEEL SCRAPER.

The four-wheel or Maney scraper was first made in 1909, and has been used in the far west in railroad work. It is used extensively in preparing the sub-grade for pavements.

155. Scraping Grader. There are several forms of scraping graders of the type shown in Fig. 23, which differ in minor details but all of which accomplish substantially the same work. Each consists of a frame carried on four wheels, supporting an adjustable scraper-blade, the front end of which plows a furrow while the rear end pushes the earth toward the center of the road or distributes it uniformly to form a smooth surface. The blade can be set at any angle with the direction of draft, or at any height; and it may also be tilted forward or backward. This machine will work in almost any soil—even where a plow will not. It is hauled by horses or traction engine, usually the former, and makes successive rounds

or cuts until the desired depth of ditch and crown of road is obtained.

This machine is often called a road grader and sometimes a blade grader; but it is here designated as a scraper grader to distinguish

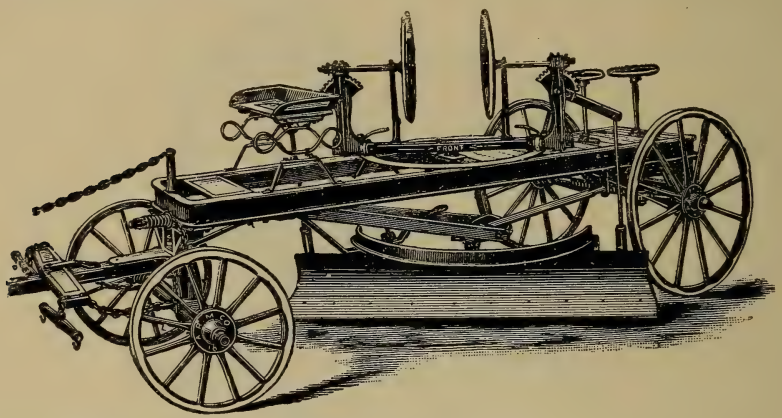


FIG. 23.—SCRAPING GRADER.

it from the elevating grader (§ 161). The scraping grader is an important machine in both the construction and the care of earth roads. As an instrument of maintenance it has been called a road hone, but could more properly be called a road plane.

Fig. 24 to 27, pages 98 to 99, show the various kinds of construction work that may be done with this type of machine. For a discussion of the work of this machine in maintenance, see § 208–11.

Various devices are employed to neutralize the lateral resistance of the earth to being pushed sidewise by the blade. In some types the whole rear end of the machine may be thrown to one side or the other by operating a hand-wheel; in other forms the rear axle is shifted lengthwise so that one wheel may bear against the unplowed bank of the ditch; in other cases either rear wheel can be moved in or out independently; in still other types either the front or rear wheels or both may be set at any inclination by operating a hand-wheel; and in other forms the wheels have a flange which cuts into the earth and resists the lateral thrust.

The scraping grader is of inestimable value in constructing earth roads, as it does the work better and much cheaper than it can be done either by hand or with plows and scrapers. The work done with the scraping grader is also superior to that done with plows and drag scrapers, since the plow cuts deeper in some places

than others and these places are left full of loose earth and soon form holes which catch and hold water.

156. There are scraping or blade graders on the market having only two wheels, and also those having no wheels; but such machines are neither common nor efficient. They have been superseded by the road drag (§ 206).

157. *Operating the Scraping Grader.* To build a road with the scraping grader, first plow a light furrow with the point of the blade, where the outside of the ditch is to be (see Fig. 24, page 98). To make the blade penetrate hard or stony ground, elevate the rear end considerably and use only the point. On the second round, with the front and rear wheels in line (see Fig. 25), drive the team so that the point of the blade will follow the furrow made the first round, plowing a full furrow with the advance end of the blade, and dropping the rear end somewhat lower than before. The third time round, move the earth previously plowed over toward the middle of the road. In moving the earth toward the center of the road, elevate the rear end of the blade to allow the earth to distribute under it, so as to build the road at the side of the proper crown before filling the center; and if the machine slides sidewise instead of pushing the ridge of earth toward the center, either slue the whole rear end of the machine toward the center, or move one hind wheel or the whole rear axle laterally until the rear wheel bears against the bottom of the unplowed bank at the ditch, or incline the rear wheels, according to the construction of the machine. Finally, return to the ditch and plow it out deeper, moving the earth over toward the middle whenever as much is plowed as the machine can move at once. Repeat this until the ditches are of the proper depth, and the road as full and round as required.

A ridge should not be left in the middle of the road. Usually a skillful handling of the machine will prevent the formation of such a ridge by elevating the rear end of the scraping blade, thus allowing the earth to lose out under it as the center of the road is approached. If the road is very rough, it may not be possible to fill all the ruts without at some places forming a ridge in the center of the road. If the ridge is formed, it can be flatted down by setting the blade square across the road and allowing the earth to flow under it; or with most machines the center ridge can be leveled down by reversing the blade and using the back of it.

If the ground where a road is to be constructed is covered with weeds and grass, it should be cleared by burning or by mowing and

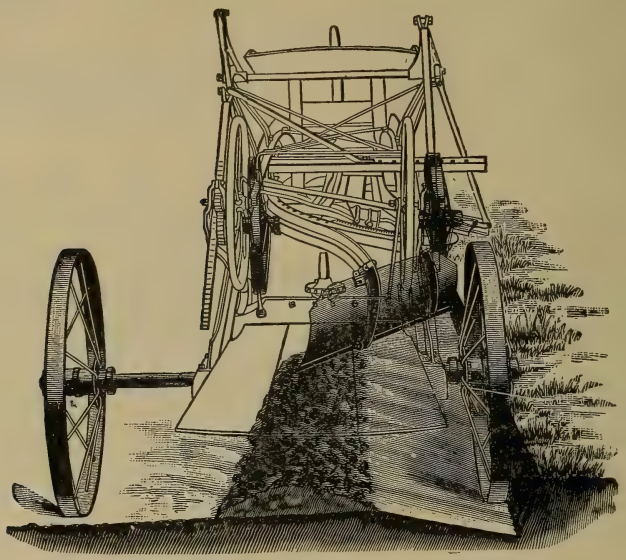


FIG. 24.—SCRAPING GRADER MAKING FIRST ROUND.

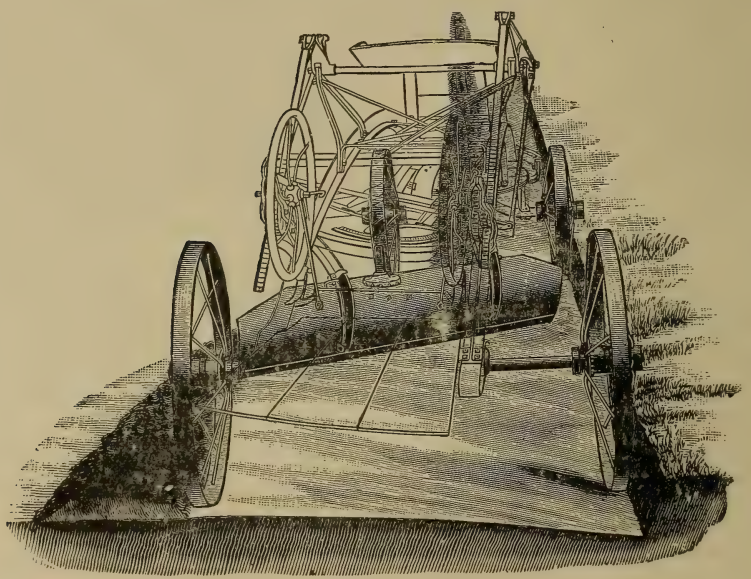


FIG. 25.—SCRAPING GRADER MAKING SECOND ROUND.

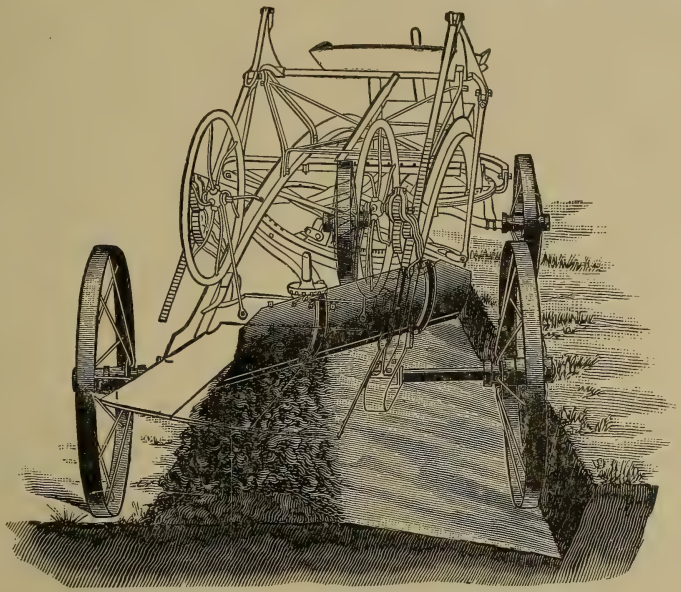


FIG. 26.—SCRAPING GRADER PLOWING BETWEEN FRONT WHEELS.

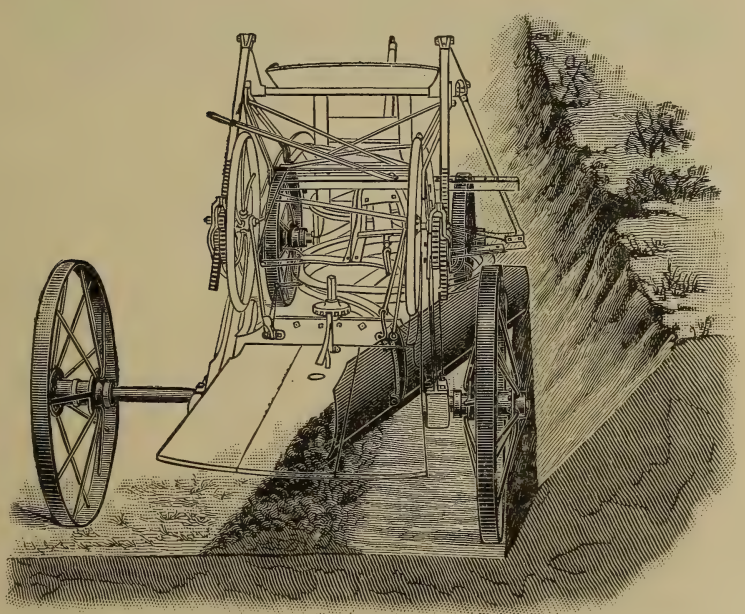


FIG. 27.—SCRAPING GRADER CUTTING AWAY OLD BANK.

raking. With sod ground the best road can be obtained by first cutting the sod as thin as possible and moving it to the center of the road, and then going back to the ditch and continuing the grading as described above. To cut a thin slice of sod, the scraper blade should be as sharp as possible. When the ground to be moved is covered with sod or weeds, some operators make the first cut on the inside of the ditch and at each successive round cut a little farther out, thus distributing the sod through the earth forming the roadway. This requires too much cutting with the unsharpened end of the blade, and is therefore not as good as the method described above.

158. It is best not to put more than 4 to 6 inches of loose earth into the road at one working, as that is all that can be thoroughly packed by traffic. If a greater amount is thrown up at one time, the bottom of the grade will remain soft and cause the road to cut into deep ruts as soon as the top has become thoroughly soaked by rain. As far as possible the grading should be done early in the summer, giving ample time for the loose earth to settle and pack before the fall rains. If worked in the fall, there should never be more than 4 inches of loose earth put upon the road at one working.

If the maximum amount of earth is to be placed upon the road at once, it is wise to roll each successive layer with as heavy a roller as is available or as a team can draw, as otherwise traffic will consolidate only the surface, and the bottom of the grade will long remain soft and spongy.

159. The scraping grader is usually drawn by four or six horses, depending upon their size, and the character and condition of the soil. One man can operate the machine, and one or two men are required to drive.

A traction engine is sometimes used; and it is a better power, since it gives a steady draft and does not need to stop to rest. At certain seasons of the year, the traction engine is the cheaper power, and at other times horses are the cheaper, depending upon the requirements of horses for farm work and the demands for the traction engine in threshing and shelling.

160. The cost of building an ordinary prairie road with horsepower with this machine is about $30 to $40 per mile, with a width of 30 or 35 feet and a crown of 6 inches above the natural surface. The first is the cost when there is no sod, and the second when there is a stiff sod. A second 6 inches may be added for about $30 per mile.

If the ground is very dry and hard, another team and driver will be required, and the above prices may be nearly doubled.

161. Elevating Grader. The best known form of the elevating grader is shown in Fig. 28. It consists of a frame resting upon four wheels, from which is suspended a plow and a frame carrying a wide traveling belt. The carrier is built in sections and its height is adjustable. The larger carrier will deliver earth 14, 17, 19, or 22 feet horizontally and 8 feet vertically from the plow; while the smaller size will deliver 14 and 17 feet horizontally and 7 feet vertically. The smaller machine is designed for highway work. The

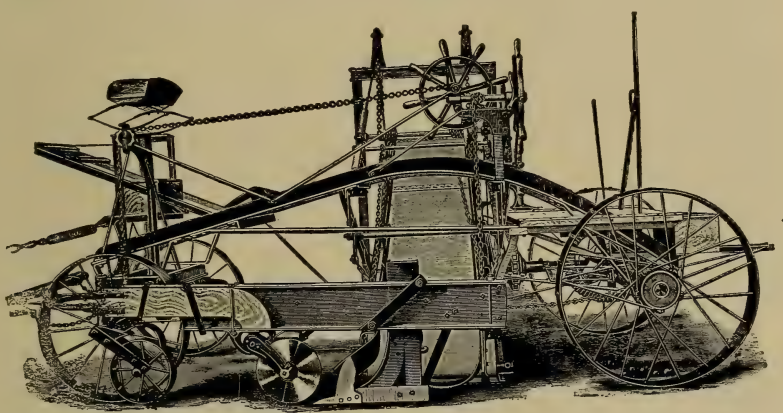


FIG. 28.—ELEVATING GRADER.

plow loosens the soil and throws it upon the traveling inclined belt, which delivers it upon the embankment direct or into wagons.

This is an exceedingly effective machine for building open ditches, earth embankments, or filling wagons. By changing the length of the carrier and by properly distributing the earth, the machine will build either a broad low embankment from a narrow deep cutting, or a narrow high embankment from a broad shallow cutting; or the machine will excavate a deep narrow ditch with flat spoil banks, or a shallow ditch with narrow spoil banks. This machine is especially adapted to building earth roads in a prairie country, for which purpose it has been very largely used.

The large machine is usually propelled by twelve horses—eight in front and four behind,—and the smaller by eight in front. Often a traction engine is cheaper than horses. One man can operate the machine; and at least two men, and usually three, are required to drive the larger machine, but usually two drive the smaller one.

162. *Operating the Elevating Grader.* To build a new road of the sections shown in Fig. 11 and 12, page 82, first mark by stakes a line 10 feet on each side of the center of the proposed road. With the machine arranged to throw the earth 17 feet horizontally, drive along the left-hand row of stakes and back on the other side of the road in the same way. The streams of earth as delivered will overlap 5 or 6 feet. Start the machine on the second round with the right-hand forward wheel in the furrow of the previous round, and complete the round. A harrow should follow the machine to break up the sod and level the bank. Continue to make rounds until the ditches are as wide as desired.

Commence the second plowing by bringing the left-hand wheel of the machine to the left-hand edge of the first furrow cut, which brings the plow one furrow to the left of the point of commencing the first plowing, and keep this relative position while making this round. Make the second round with the left-hand forward wheel in the furrow of the previous round; and continue to make rounds until the outside of the ditch is reached again. For the best results a harrow and roller—the heavier the better—should follow the grader during the second and subsequent rounds—see Fig. 29.

When the second plowing has been completed, the grade will be

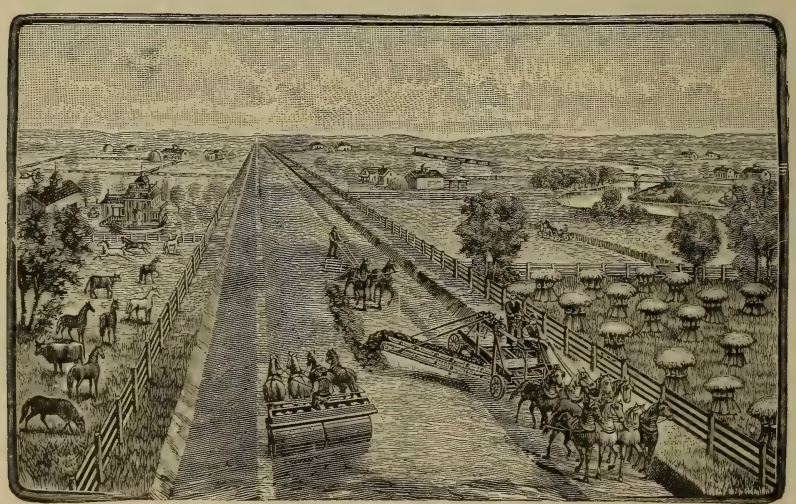


FIG. 29.—ELEVATING GRADER BUILDING EARTH ROAD.

high and narrow; and therefore the carrier should be shortened to 14 feet. Then start the machine so that the plow will take a furrow

from the center of the ditch, and continue the third plowing, as described above for the first and second, to the outside of the ditch. For the fourth plowing take a couple of furrows from the outside of the excavation to deepen the ditch.

The final result should be about as in Fig. 11 or 12, page 82. Most operators, however, leave a berm at the inside edge of the ditch (Fig. 37, page 122), which is undesirable since it interferes with the operation of the scraping grader in maintaining the road.

163. For loading wagons, the carrier is arranged to deliver at 17 or 19 feet horizontally from the machine, the wagons are driven so that the earth falls from the carrier into the wagon, and both move at the same speed until the wagon is loaded; and then the grader slows down while the loaded wagon drives out and an empty one drives in. Common wagons with dump boards are not so easily loaded as the usual dump wagon, since they are narrower and longer. It is customary to estimate three dump wagons for the first 100 feet of haul, and an additional wagon for each 100 feet thereafter.

164. Cost of Earthwork. Of necessity, general estimates of the cost of earthwork can not be very exact, since the cost will vary with the condition of the soil, the wages, the hours constituting a day's work, the relative amount paid for supervision, the effectiveness of the supervision, the facilities for preventing one part of the crew from interfering with the work of another, the proper adjustment of the number of shovelers per wagon or cart, or of scraper holders to scrapers, etc. The following data have been checked by engineers and contractors of wide experience and are believed to be reasonably reliable.*

165. In the analysis of the cost of earthwork to follow, the price for a man will be assumed to be $1.50 per day of 10 hours, and that for a team and driver $3.50 per day. These were the usual wages formerly paid by contractors, which are the prices to be considered here; for if the work is done under the labor-tax system ordinary estimates will not apply (§ 51–52), and if the farmer hires out to do the work of a teamster he usually demands the ordinary pay for that class of work. These were about the prices current for a number of years in a number of states, before the rise of prices incident to the Great European War. Of course, if wages are greater than as stated above, the following prices can be changed proportionally.

166. Cost with Scraping Grader. In prairie soil, two men and

* For an instructive discussion of methods of Handling Earth in Road Construction, see an article by Chas. R. Thomas in *Engineering and Contracting*, Vol. 47 (1917), pp. 406–08.

four horses with a scraping grader can build a mile of road 36 feet wide from inside to inside of ditch with a crown of 6 inches at the center after being compacted, for $30 to $40, which is equivalent to $1\frac{2}{3}$ or $2\frac{1}{4}$ cents per cubic yard. The first is the cost when there is no sod, and the last when there is sod. The cost for a crown of 12 inches will be about $70 per mile, or $1\frac{3}{4}$ cents per cubic yard. The above prices do not include interest, or wear and tear of grader, which would be about $\frac{1}{5}$ cent per cubic yard.

In hard soil requiring an extra team and hence another driver, add one half to the above prices.

167. Cost with Elevating Grader. The elevating grader, Fig. 28 and 29, pages 101 and 102, will, in light prairie soil, deposit on a road 1,000 cubic yards per day of 10 hours; and will load into wagons 500 yards per day. The outfit required is: seven two-horse teams at $2.50 each *plus* 2 drivers at $2.00 each *plus* 1 operator at $2.00 and 1 at $2.50 = $29.50. For the earth deposited on the road this is 2.9 cents per cubic yard, and for that loaded into wagons 5.8 cents, exclusive of interest, depreciation, and administration.

168. Cost with Drag-Scoop Scraper. Drag scrapers are admirably adapted for borrowing at the sides of embankments and for wasting from cuts or ditches, and also for opening the mouth of large cuts; but are not economical except for short distances. There is no danger of the scraper getting out of order until it is worn out and unfit for use, and the manner of using it is quickly learned by any one. Drag scrapers are made in three sizes having a capacity of 3, 5, and 7 cubic feet, respectively; but it must not be assumed that each scraper will carry to the embankment an amount equal to its rated capacity, since in the first place it is difficult to completely fill the scraper, and in the second place the scraper carries loose earth which will shrink about 25 per cent when compacted in the embankment. Unless the soil is very loose and easily loaded, it is not safe to assume that each trip of the scraper will make of completed embankment more than one half of its rated capacity. The larger size is most economical, but the relative advantage is not proportional to the size, since the larger size is not as easy to handle nor as easy to fill. Scrapers should be used in gangs of not less than six to decrease the cost of loading, superintendence, spreading, etc.

169. *Cost of Loosening.* Sand or sandy loam can be scraped without plowing. In loam a two-horse team and plow will loosen 400 cubic yards per day, at a cost of $3.50 for team, plow, and driver,

and \$1.50 for the plow holder, making a total of \$5.00, or $1\frac{1}{4}$ cents per cubic yard. Sometimes the driver can also hold the plow, in which case loosening will cost about 1 cent per cubic yard, since the team will not do quite as much work as when there is a plow holder and also a driver. If the ground is hard it will be necessary to add another team and also a man to "ride" the beam of the plow. If the ground is not very hard, this force will loosen 400 cubic yards per day at a cost of 2.1 cents per yard.

170. *Cost for 25-foot Haul.* The cost of building an embankment from a borrow pit at the side of the road will first be considered. For a 60-foot right-of-way and a light embankment, the length of haul or "lead" from center of gravity of the fill to the center of gravity of the cut will be about 25 feet. This distance will be a little more or a little less according to the height and width of the bank, and the width reserved for sidewalk; but slight difference in length of short hauls make comparatively little difference in the cost of moving the earth, because in the first place a considerable part of the cost of hauling is due to time consumed in turning and loading, and in the second place the cost of transportation is only about half the total cost of moving the earth.

On the road, an ordinary team will travel 220 feet per minute ($2\frac{1}{2}$ miles per hour), but in scraping considerable time is consumed in turning, waiting to load, etc., and besides, the distance traveled is more than that from the center of cut to the center of fill; therefore the ordinary speed of the team is no guide in this connection. Experience shows that a team will use from a minute to a minute and a half in making a round trip at the above distance, or, say, $1\frac{1}{4}$ minutes per trip. A foot vertically is equivalent to 10 to 25 feet horizontally (see § 77), and in estimating the length of haul this fact must be taken into account.

Using the large scraper, a scraperful will make $3\frac{1}{2}$ cubic feet of compacted embankment, or will require eight trips per cubic yard. Therefore a team will place a yard of earth in the fill every 10 minutes, or 6 yards per hour and 60 yards per day. In light loose earth, where it is easy to fill the scrapers full, a team may make 70 yards; but if the ground is hard, or obstructed with roots and grass, 50 yards may be the maximum. Assuming a day's work to be 60 yards, the cost of hauling is $\$3.50 \div 60 = 5.83$ cents per cubic yard.

One man will hold and fill the scraper for two teams at a cost of $\$1.50 \div (2 \times 60) = 1.25$ cents per yard. One man on the dump

will distribute and level the earth deposited by six teams, at a cost of $\$1.50 \div (6 \times 60) = 0.4$ cents per cubic yard. One foreman will be required at, say, $2.50 per day; or $\$2.50 \div (6 \times 60) = 0.69$ cents per cubic yard. For wear and tear of scraper we may allow 10 cents per day for each, or 60 cents for the lot; and for wear of plow and cost of sharpening, say, 30 cents, making a total of 90 cents or 0.25 cents per cubic yard. In very hard ground the above prices may be doubled.

The total cost of moving earth 25 feet will then be as in Table 18, page 108.

171. *Cost for* 50*-foot Haul.* We will next consider the cost for a 50-foot haul. At this distance a scraper holder can fill for three teams. Each team can put in about 50 cubic yards per day. The other items will be substantially as for a 25-foot haul, and the total cost will be as in Table 18.

172. *Cost for* 100*-foot Haul.* Each team will make a trip in about $2\frac{1}{2}$ minutes, and will put in 40 cubic yards per day. The total cost will be as in Table 18.

173. *Cost for* 200*-foot Haul.* At this distance a scraper holder can fill for four teams. Each team will make the trip in about $3\frac{1}{2}$ minutes, and put in about 35 cubic yards per day. The total cost will then be as in Table 18.

174. *Cost for Hard Ground.* If the ground is so difficult to plow as to require a second team and a man to ride the beam, add 1 or $1\frac{1}{2}$ cents to the values in Table 18 for the extra cost of loosening; and add, say, one fifth to the cost of hauling to allow for the fact that in hard ground the scrapers are not as well filled as in loose light soil. Also add one half to the above estimated cost of wear and tear. The results for hard ground are then as in Table 18.

175. Cost with Two-Wheel Scrapers. Two-wheel scrapers are excellent for hauling earth distances up to 600 or 700 feet. They are made in three sizes, No. 1, 2, and 3, having a capacity of 9, 12, and 15 cubic feet, respectively. With No. 1 the team fills its own scraper, while with No. 3 an extra team (a snatch team) is required to fill the scrapers reasonably full; and unless the ground is very loose and light an extra team is required to fill No. 2. Most contractors use either No. 1 with a single team or No. 3 with a snatch team. It usually takes about five loads with No. 1 to make a cubic yard in place; four, with No. 2; and three, with No. 3.

176. *Cost for* 100*-foot Haul.* It is assumed that the scrapers will be worked in a gang of six, which will require one foreman, one

plow, three scraper holders, and one man on the dump. The expense for these items will be the same as for the drag scrapers, and are so entered in Table 19, page 109. At this distance a trip will occupy $2\frac{1}{2}$ minutes, and a yard will be deposited every 10 minutes, or 60 yards per day, at a total cost $3.50, or 5.83 cents per cubic yard for hauling.

The wear and tear is computed on the assumption that a scraper will last for 200 days' continuous work, making a cost for depreciation and repairs of, say, 20 cents per day per scraper. The wear and tear on the plow will be estimated at 30 cents per day. The total cost will then be as in Table 19.

177. Notice that the cost for 100 feet with the two-wheel scraper is 9.99 cents per cubic yard, while with the drag scraper for the same distance it is 12.67 cents. The difference is in the cost of hauling, which is due to the difference in the capacity of the scrapers.

178. *Cost for* 200-*foot Haul.* A trip will be made in about 4 minutes, and each scraper will put in 50 cubic yards per day. The three scraper holders can fill an additional scraper, making nine in all. The cost will then be as in Table 19.

179. *Cost for* 300-*foot Haul.* In this case another scraper can be added, making four scrapers to each scraper holder. A trip can be made in about $5\frac{1}{2}$ minutes, and each team will move 45 yards per day. The cost will be as stated in Table 19.

180. *Cost for* 400-*foot Haul.* It is difficult to determine the most economic distance for each size of scraper, since the several sizes are seldom available for making the test. However, at 300 feet, the cost with a No. 2 scraper is about the same as with a No. 1 at 200 feet; and at 400 feet the cost with a No. 2 is about the same as with a No. 1 at 300 feet. But at 400 feet a No. 3 is more economical than a No. 2.

A snatch team is required in filling No. 3 scrapers. The extra force acquired by using the extra team completely fills the scraper, and also packs the load so that it is less liable to spill than when loaded by a single team. For this distance it is most economical to work the scrapers in a gang of eight; and two men will be required to hold the scrapers while being filled. Each team will put into place 45 cubic yards, or 360 for the gang. The total cost will be as shown in Table 19.

181. *Cost for Other Distances.* For each additional 100 feet of lead, add 1 cent per cubic yard to the cost of haul; and the total cost will be approximately as shown in Table 19.

TABLE 18

COST OF MOVING EARTH WITH DRAG-SCOOP SCRAPER

Cents per Cubic Yard

Ref. No.	Items.	25-ft. Haul.		50-ft. Haul.		100-ft. Haul.		200-ft. Haul.	
		Loose Earth.	Hard Ground.	Loose Earth.	Hard Ground.	Loose Earth.	Hard Ground.	Loose Earth.	Hard Ground.
1	Loosening	1.25	2.50	1.25	2.50	1.25	2.50	1.25	2.50
2	Filling scrapers	1.25	1.50	1.00	1.50	1.00	1.25	1.00	1.00
3	Hauling	5.83	6.50	7.00	7.70	8.75	9.62	10.00	11.00
4	Leveling	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
5	Superintendence	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69
6	Wear and tear	0.25	0.38	0.33	0.50	0.42	0.63	0.53	0.80
7	Water boy	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
8	Total cost	9.83	12.13	10.83	12.95	12.67	15.25	14.03	16.55

TABLE 19.

COST OF MOVING EARTH WITH TWO-WHEEL SCRAPERS

Cents per Cubic Yard

Ref. No.	Items.	Length of Haul in Feet.							
		Using Scraper No. 1.			Using Scraper No. 3.				
		100	200	300	400	500	600	700	800
1	Loosening	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
2	Filling scrapers	1.25	1.00	1.00	1.80	1.80	1.80	1.80	1.80
3	Hauling	5.83	7.00	8.00	7.77	8.77	9.77	10.77	11.77
4	Leveling	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
5	Superintendence	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69
6	Wear and tear	0.41	0.58	0.75	0.53	0.64	0.75	0.86	0.97
7	Water boy	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
8	Total cost	9.99	11.08	12.25	12.60	13.71	14.82	15.93	17.04

When the amount of earth to be moved is considerable and the length of haul is great, something must be allowed for keeping in repair the road over which the earth is transported. A wheel scraper is prone to wear a series of humps and hollows along the road it traverses, and these must be kept in subjection, if the work is to be done at reasonable cost. The proper allowance will vary greatly with the soil, the weather, etc. Trautwine recommends 0.1 cent per cubic yard per 100 feet for this expense.

182. It is difficult to determine at what distance wagons should supersede two-wheel scrapers; but usually the economic limit for two-wheel scrapers is 600 to 800 feet, and it is seldom wise to use such scrapers beyond 800 feet—unless they are at hand and wagons are not.*

183. Cost with Four-Wheel Scrapers. The cost of moving earth with the four-wheel scraper is not well established. With enough scrapers to keep the loading engine reasonably busy, the cost of power for loading—operator, fuel, rent, etc.,—will be about 2 or 3 cents per cubic yard, depending upon the hardness of the soil. The saving in loading is 5 to 6 cents over that of wagons—see § 184.

184. Cost with Wagons. It will be assumed that the wagons are filled by hand, that they are used in gangs of nine, and that the haul is 700 to 800 feet. If the roads are level and fairly smooth, a load will make about $1\frac{1}{4}$ cubic yards in place; and with ordinary roads, 1 yard will make a load; but if the roads are soft and steep, $\frac{2}{3}$ of a yard may make a load. The amount a team can deliver will vary greatly with the time consumed in waiting to load and in loading. With short wagon-hauls and well-organized work, half of the time is thus consumed, and often much more is thus consumed. The time of the wagon while loading should be considered as a part of the cost of loading, and this will be discussed more fully in the next paragraph. For the above distance, the round trip will consume 15 minutes; and assuming a yard as a load, each wagon will deliver 50 cubic yards per day, at a cost of 7.00 cents per cubic yard for hauling.

There is very great variation in the amount of earth a shoveler will load in a day. In well managed work, the shovelers are not

* For the results of an elaborate time study of cost of moving various kinds of soils different distances with two-wheel scrapers and Fresno scrapers, see *Engineering and Contracting*, Vol. 41 (1914), pp. 629–36.

actually engaged in loading much more than half of the time; while under poor management, they do not really work half of the time. With short intervals of rest equal to the working time, a man should load, in a day of 10 hours, 20 cubic yards of light sandy soil, 17 yards of loam, and 15 of heavy soil—provided all are loosened by plowing or picking. Usually five or seven men are set to load a wagon—two or three on each side and one at the rear. Seven men will load a wagon with loam in 5 minutes, 8 minutes will be consumed in traveling to and from the dump, 1 minute in dumping and 1 minute in getting into and out of the cut—making in all 15 minutes for a round trip; and therefore the cost for wagon and team is 8.75 cents per cubic yard, as above. In this case the team works only about half the time. If only five men are engaged in loading a wagon, 7 minutes will be consumed in loading, and the time for a round trip will be 17 minutes, and each wagon will deliver only 35 cubic yards, making the cost 10 cents per cubic yard. In this case, the team really works less than half the time. If the men shovel only 12 to 15 cubic yards each, as is very common, the loss by the wagon's waiting for a load is considerably more than above. The proper number of men to be set to loading a wagon depends upon the relative wages of shoveler and wagon, upon the length of the haul, and upon the quantity loaded per day per man. Usually seven shovelers are employed to each wagon, but this number is not enough to secure the greatest economy. In the following estimates it will be assumed that nine shovelers are employed to each wagon. At the above distance, nine shovelers, each loading 17 yards per day, will be required to keep three wagons going, each of which deposits 45 cubic yards per day. The cost of loading will then be 8.8 cents per cubic yard.

The cost of leveling the dump is small, if dump wagons are used and the earth is dumped over the end of the embankment or wasted; and it may be taken the same as for scrapers. i. e., at 0.40 cents per cubic yard. But dump wagons are so heavy and expensive that they are seldom used; and if ordinary wagons with dump boards are employed, the expense for labor on the dump will be about three times as great as above, or, say, 1.20 cents per cubic yard.

The driver furnishes his own wagon, and hence no account is taken of the wear and tear of it. There should be a small allowance made for the wear and care of shovels, say, 0.1 cent per cubic yard.

The total cost of moving earth 700 to 800 feet with wagons, then, is as follows:

1. Loosening	1.25	cts. per cu. yd.
2. Shoveling	8.80	" "
3. Depreciation of shovels	0.10	" "
4. Hauling 700 to 800 feet	7.00	" "
5. Helper on dump	1.20	" "
6. Superintendence	0.69	" "
7. Water boy	0.16	" "
Total cost	18.20	" "

185. For longer distances add 1 cent per cubic yard for each 100 feet of distance—the usual charge for over-haul.

186. Other Methods. When the haul is more than 600 or 800 feet, and when the amount of work to be done is sufficient to justify the initial expense, it is more economical to use portable track and small dump cars than to use wagons. However, such conditions seldom occur in wagon-road construction.

187. Finishing the Slopes. In addition to the elements of cost discussed above, there is always some expense in leveling off the bottom of the cut, in digging ditches, in trimming up the slopes of embankments and excavations, and in cutting a catch-water at the top of the slope in excavation. The cost of these items will very greatly with the degree of finish required and also with the depth of the cut or the fill; and it may amount to 0.25 or 0.50 of a cent per cubic yard. If the bottom of the cut can be leveled off with the scraping grader, and if the ditch also can be made with this machine, the cost of this item will be considerably reduced.

188. Profits and Administration. The proper allowance under this head will vary according to the magnitude of the work, the risks involved, etc.; but will usually be 5 to 15 per cent. Out of this the contractor must pay the expense of assembling the plant, the cost of tool house, the wear and tear on small tools, interest on investment, profits, etc.

189. BRIDGES. This subject will not be considered here, since the space available is not sufficient, and since there are a number of elaborate treatises on bridges. None of these, however, gives an adequate treatment of the very small highway bridge, or fairly represents current practice for moderate spans.

190. WATERWAYS. The determination of the amount of waterway required for any particular bridge or culvert is a matter of importance. Although the problem does not admit of an exact mathematical solution, it requires intelligent treatment. For a discussion of this subject, see pages 564–69 of the tenth edition of author's Masonry Construction.*

191. CULVERTS. For a discussion of the cost and method of construction of culverts—wood box, vitrified pipe, cast iron pipe, stone box, and masonry-arch culverts,—see the author's Masonry Construction, pages 569–605.*

One common defect of earth roads is that culverts are made too short, which concentrates the traffic upon the portion of the road usually least able to bear it. A short culvert may be permissible when the cost per unit of length is great, but the defect is common where this cost is quite small.

192. RETAINING WALLS. Retaining walls are masonry structures employed to support the sides of roads on hillsides or in places where land for the ordinary earth slopes is not readily obtainable. For a discussion of retaining walls, see the author's Masonry Construction, pages 489–534.*

193. GUARD RAILS. Roads on steep hillsides or on high embankments, and particularly on sharp curves in mountain roads, should be protected to insure vehicles against the possibility of falling down the slope. In Europe such protection is usually afforded by a stone wall, or by stone posts set at frequent intervals. In this country the usual protection is by means of wood posts and wood guard rails. The description of the guard rails used on the state-aid roads in Massachusetts is as follows: "Posts of cedar, or other wood which endures well in the soil, are set at intervals of 8 feet, and 1 foot in from the edge of the embankment. These posts are planted to the depth of 3 feet, and project for 3 feet 6 inches above the ground. The top of this post is transversely notched, so as to receive one half of a rail 4 inches square. Half-way down, the post is notched to receive another rail 2 by 6 inches in size. These rails, preferably of planed spruce wood, are spiked to the posts. To insure the better preservation of the wood and it visibility in the night-time, it is painted with two coats of oil paint of some light color." For a diagram of this guard rail, see Fig. 52, page 198.

* A Treatise on Masonry Construction, by Ira O. Baker, 745+xv pp., 6×9 inches, cloth, 10th edition. John Wiley & Sons, New York. Price $5.00.

The Massachusetts Highway Commission wherever practicable widens the base of the embankment until a slope of 1 to 4 is obtained, and then dispenses with the guard rail. This plan is believed to be more economical, and to give a better appearance.

194. GUIDE POSTS. Some states, by statute, require guide posts at all intersections; and their value to the occasional traveler is sufficient to justify the expense. The guide post may be a plain post, supporting near its top a board upon which is the name of the place reached by the road, with figures showing the distance, and a ☞ to show the direction.

195. ARTISTIC TREATMENT. Engineers are accustomed to study chiefly or only the economic side of construction, and are therefore likely to neglect the artistic treatment of the highway. In the attempt to beautify the roadside, it may be necessary to sacrifice a little of utility to secure a pleasing effect. Masses of foliage and shade add beauty to the roadside, but tend to keep the traveled way damp—usually the bane of good earth roads. Trees are a necessary adjunct to a beautiful highway, but are anything but a benefit to the traveled way. If beauty is desired at the expense of utility, highways can scarcely be too much shaded by over-arching boughs. However, a happy medium will suffice in most places.

The varieties of trees suitable for the ornamentation of highways are almost infinite. The elm, with its graceful arching branches and delicate lace-like foliage, is not surpassed; and the hard maple and the oaks are very handsome for this purpose. The walnut, the butternut, the hickory, the beech, the poplar, and the pine, ranging from the most delicate to the most somber and rugged, are all more or less adapted to particular requirements and circumstances. Trees such as willow, the roots of which spread extensively or seek water vigorously, should not be permitted to grow near tile drains, as the small roots frequently entirely obstruct the tile. Trees should not be planted close to the traveled way, but near the edge of the right-of-way, or if possible on the private property bordering the right-of-way.

196. The roadside fences are usually the property of the adjoining land owner, and may mar or beautify the landscape. The hedge rows of England and the stone fences of New England are all that can be desired for appearance; but in localities where there is much snow they catch the drifting snow and so obstruct the highway. The only thing favorable to the appearance of the common wire fence is that it is inconspicuous.

ART. 2. MAINTENANCE

197. Proper maintenance is as important as good construction. A distinction should be made between maintenance and repairing. The former keeps the road always in good condition; the latter makes it so only occasionally. If the road is not properly maintained, it deteriorates in a geometrical ratio. A small depression fills with water and soon becomes a mud hole which travel makes deeper and deeper; or an obstructed side ditch forces the water to run down the center of the road, and gullies out the surface. A defect which could be remedied in the beginning with a shovelful of earth and a minute's time, if neglected may require a wagon load of earth or an hour's time, besides being in the meantime an annoyance or a damage to travel. The better the state in which a road is kept, the less are the injuries to it by ordinary travel and the weather.

198. DESTRUCTIVE AGENTS. The agents tending to destroy the road are: water, narrow tires, the tracking of the front and rear wheels, the horse not being hitched before the wheel.

199. Water. Water is the natural enemy of good earth roads. The chief object of maintenance should be to keep the surface smooth and properly crowned so that rain will be shed into the side ditches. These should be kept open so that the water may be carried entirely away from the road. This subject is fully considered in § 205–15.

200. Narrow Tires. It is desirable that a wagon in passing over the road should help to make or preserve it, and not to destroy it; and therefore as far as the road is concerned, within reasonable limits, the broader the tire the better.

Tables 3 and 4, pages 15 and 16, show the relative tractive resistance of broad and narrow tires. Although there is not much difference between the tractive power of broad and narrow tires, the latter are much more destructive on any road, particularly on an earth one. But in deciding upon the proper width of tire, there are other factors besides the tractive resistance and the preservation of the road, that must be considered.

If wagons were employed only upon the public highway, it might be wise to use wide tires and sacrifice some tractive power for the benefit of the roads. Other things being equal, a wagon with broad tires is not so easily managed as one with narrow tires. To be equally easy to turn, the broad-tired wagon should have a narrower bed, or a longer front axle, or a smaller front wheel. In

Europe it is customary to adopt the smaller front wheel, which is very destructive of the broken-stone roads so common in that country. Increasing the length of axle interferes with getting the wagon up to cribs, warehouses, etc., and increases the difficulty in going through gates, passing buildings, etc. It is not clear that laws should be passed regulating the width of tires, many claims to the contrary notwithstanding.

"The best argument against the enactment of laws concerning broad tires is found in the fact that the numerous and long-enforced English statutes on this matter have of late years been abrogated, a century of experience having shown that they are difficult to administer and generally disadvantageous." The Massachusetts Highway Commission, after an elaborate discussion of the subject,* says: "It is a matter of doubtful expediency to endeavor, in the present state of our highways, by general legislation to control the width of tires or the diameter of wheels."

201. Many European countries have laws regulating the width of tires. In England for 100 years the law required 1 inch of tire for each 500 pounds of load, but all general laws in that country regulating the width of tires have been repealed. In France the tires of market carts vary from 3 to 10 inches in width, being generally from 4 to 6 inches, with the rear axle about 14 inches longer than the forward one.

In this country a number of the states have statutes concerning the width of tires, many of which take the form of a rebate, either cash or part of the road tax, to those using tires of a prescribed width. The following is the legal width in Ohio for vehicles using gravel or broken-stone roads:

Minimum width of tire for load of			2,500 to 3,500 lb	3	inches
"	"	"	3,500 " 4,000 "	$3\frac{1}{2}$	"
"	"	"	4,000 " 6,000 "	4	"
"	"	"	6,000 " 8,000 "	5	"
"	"	"	8,000 or more "	6	"

According to wagon manufacturers about 60 per cent of the wagons used on country roads have tires $1\frac{1}{2}$ to $1\frac{3}{4}$ inches wide, those of the remaining 40 per cent being 2 to 4 inches. The broad tire is of comparatively recent introduction on rural roads in this country.

202. There is greater justification for limiting the load per unit of width of tire on pavements than on earth roads, since with the

* Report of the Massachusetts Highway Commission for 1893, p. 56–62.

latter the damage is not so great and can be more easily repaired. For a discussion of limiting loads on pavements, see § 39. Notice, however, that these regulations apply only to loads heavier than any likely to traverse earth roads.

203. Equal Axles. Since with equal axles the hind wheel follows in the track of the fore wheel, it increases the depth of the rut, and consequently increases the destructive effect of the wagon upon the road. The remedy would be to make the lengths of the two axles unequal, but this would make the wagon more difficult to manage and would also increase the tractive resistance. The advantage of not permitting one wheel to exactly follow another, is shown by the fact that there are no ruts at a corner or a sharp turn in the road; but it is not practicable to secure this advantage generally, either by making the two axles of unequal length or by preventing a wagon from traveling in the ruts already made.

204. Horse not Hitched before Wheel. On broken-stone roads, the horses' feet loosen fragments of stone, which tends to destroy the surface; and if the horses were hitched directly in front of the wheels, the stones loosened by the horses' feet would be rolled down by the wheels of the wagon. This is a matter of some moment with broken-stone roads, but is not important with earth roads. However, a few teamsters using earth roads hitch their horses in front of the wheel, to enable their horses and wheels to run in the beaten track made by the feet of preceding horses not hitched in front of the wheel.

205. Care of the Surface. The most important work in maintaining an earth road is to keep the surface smooth so that the rain water will flow quickly into the side ditches. If the surface of an earth road is properly formed and kept smooth, the water will be shed into the side ditches and do comparatively little harm; but if it remains upon the surface, it will be absorbed and convert the road into mud.

There are three classes of machines in use for filling ruts and depressions and in keeping the surface smooth. They are the road drag, the scraping grader, and the V road-leveler.

206. Road Drag. The road drag is the simplest, the cheapest, and the most effective implement for smoothing the surface of a road. Four type forms of the road drag are shown in Fig. 30, 31, 32, and 33, pages 118 and 119. Each consists essentially of one or more cutting edges which stand obliquely across the road as the implement is drawn along the road. The road drag is designed to do

three things, viz., (1) smooth the surface by paring off the high places and filling up the low spots; (2) move a little earth toward the center of the road to compensate for the wash of the water in reducing the crown; and (3) puddle or harden the surface by dragging it when wet. To accomplish the first purpose, the cutting edge must make a considerable angle with the line of draft, so that the earth that is pared from the high places will drift along in front of the cutting edge and fill up the low spots. To secure the second object, the front end of the cutting edge should be toward the outside of the traveled way, so the drifted earth will be moved toward the center of the trackway. To accomplish the third purpose, the road should be dragged when it is wet. Working the soil when it is wet, puddles it; when it dries, it will be hard and more nearly waterproof. Under favorable conditions each successive dragging adds a thin layer of tough and impervious material; and consequently the frequent dragging of an earth road builds up a crust that does not easily become muddy.

The slicker, or lapped-plank drag, Fig. 30, is easily and cheaply made; and is to be preferred when the road is quite soft, and also in soil that is too sticky to flow along the blade of the other forms of drags. In these cases the slicker smooths the road partly by com-

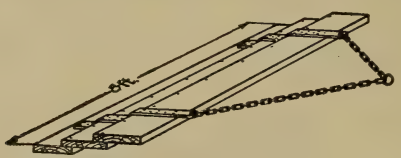


FIG. 30.—ROAD SLICKER.

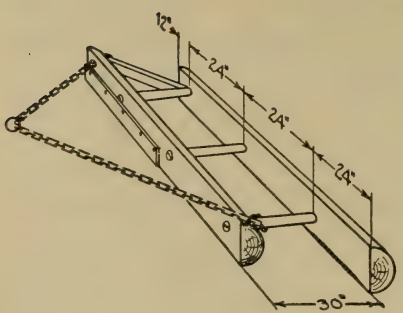


FIG. 31.—SPLIT-LOG ROAD DRAG.

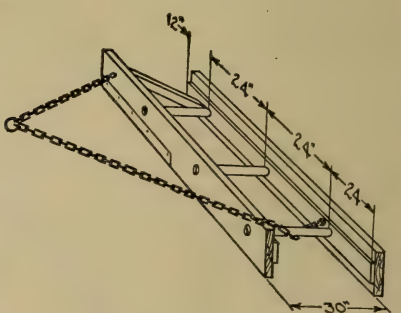


FIG. 32.—PLANK ROAD DRAG.

pressing the high places and partly by cutting them off, and thus fills up the low places and gives the water an opportunity to run off.

The split-log drag, Fig. 31, is commendable chiefly because of the ease with which it can be made when a suitable log is at hand. The log should be 7 or 8 feet long, and 10 or 12 inches in diameter. The braces between the two halves of the log may be roughly hewn and the ends be made to fit into 2-inch auger holes in the slabs. The braces should be long enough to hold the two slabs about 30 inches apart. The braces should be fastened in place by driving wedges

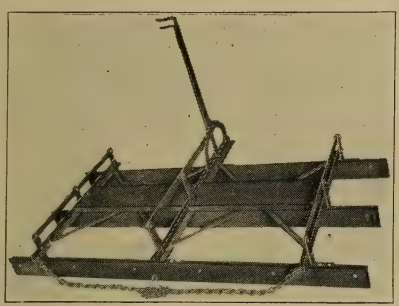


FIG. 33.—ADJUSTABLE THREE-BLADE STEEL ROAD DRAG.

FIG. 34.—ROAD SLICKER AT WORK.

FIG. 35.—WORK OF ROAD SLICKER.

FIG. 36.—SPLIT-LOG DRAG AT WORK.

into their outer ends. Fig. 36 shows a crude split-log with removable platform doing excellent work.

The dimensions and construction of the plank drag are shown in Fig. 32. If the main planks are hard wood and $2\frac{1}{2}$ or 3 inches thick, the reinforcing planks may be omitted.

Fig. 33 shows an adjustable steel road drag. The cutting blades can be tilted forward or backward by the hand lever. Similar steel drags are made with two blades. Non-adjustable 2-blade and 3-blade steel road drags also are upon the market.

207. *Rules for Using Road Drag.* The following rules should be observed in dragging earth roads:

1. Remove all loose stones from the road before dragging it.

2. The depth of cutting may be regulated by the length of the hitch chain. A short chain causes an uplift, and hence a lighter cut; and vice versa, a long hitch causes less uplift, and hence a deeper cut. The depth of cut can also be varied by the driver moving forward or backward on the drag, or even by inclining his body.

3. The driver should stand upon the drag, and be ready to shift his position as the circumstances demand. However, if an unusually soft portion of the road is encountered, it may be best for the driver to walk.

4. Drive the team in a walk.

5. Drive a horse on each side of the right-hand wheel track, with the front end of the cutting edge on the outside of the traveled way, and proceed to the end of the portion of the road to be dragged; and then on the return do similarly for the other wheel track. Of course, if the traveled way is wide, it may be necessary to make more than one round trip.

6. The best time to use the drag is when the road is drying out, while the soil cuts easily, and is damp or wet enough to puddle; but the soil should not be so sticky as to cling to the cutting edges of the drag.

7. Do not move too much earth toward the center of the road. There are two reasons for this rule. First, it is important to keep the road surface as hard as possible, and hence no more earth should be loosened than just enough to make the surface smooth. An excess of loose earth will make the road dusty in dry weather and muddy in wet weather. Second, only enough earth should be moved toward the center to counteract the effect of the rain in reducing the crown. An excess crown will concentrate travel at the center and cause deep ruts to form, which will hold water and make mud. If the crown becomes too high, drag it once or twice in such a way as to work the soil away from the center.

8. By hitching the team close to the front end of the drag, the blade will cut like a plow; and the machine can then be used to remove weeds or deepen the side ditch. With this hitch, the driver should stand near the forward end of the blade, and should throw his weight forward or backward as the work may require. Care must be taken that the entire drag is not tipped over forward. When weeds clog the cutting edge, they can be removed by the driver's shifting his weight to the rear end of the cutting edge.

9. The road should be dragged after it has been roughened by being used when muddy; but the dragging should not be postponed until the soil has ceased to be mellow and easily moved. It is a waste of time to postpone the dragging until the road has become dry and hard.

10. The most effective time to drag a road is in the spring immediately after the frost is out.

11. If the roadway is very rough and contains many deep ruts and holes, it may be best to drag it when it is quite slushy. In this case a lapped-plank smoother, or slicker, is better than the split-log, plank, or steel drag. The hitch to the slicker should be such that the outer end of the machine is a little ahead, so as to fill up the holes and ruts.

12. If a slushy road is dragged or smoothed just before freezing weather, the surface will freeze and make a fine, smooth, hard road.

208. *Cost of Dragging.* The cost of dragging the road depends somewhat upon the condition of the road and also upon the demand for men and teams for agricultural work; but usually the cost per mile per round trip of an 8-foot drag will be about 50 to 60 cents. See § 229 for further details.

209. Scraping Grader. This machine is described in § 155–56, and its use in road construction is explained in § 157–60. It is proposed here to consider the use of this machine in the maintenance of a road.

If the road drag (§ 206) were frequently and efficiently used, the road would be kept in a fairly good condition; but for one reason or another, the roads are not usually dragged when the work can be done most efficiently, and consequently are allowed to dry out rough and full of ruts. After they have reached this stage, it is nearly or quite impossible to secure a smooth surface with any form of road drag. Under these conditions the surface can be restored by running a scraping grader over the road so as to plane off the ridges and fill up the ruts.

210. *Operating the Scraping Grader.* Commence at the ditch and work toward the center, scraping with the entire length of the blade. The blade should stand nearly square across the road, and considerable earth should be shoved along in front,—enough to fill the depressions;—but only enough earth should be moved toward the center of the roadway to replace that washed down by the rains. The surplus earth should be uniformly distributed over the surface, by carrying the rear end of the blade a little higher than the point. A

ridge of earth should not be left in the center of the road, since it will but slowly consolidate and is likely to be washed into the side ditches to make trouble there.

This work should be done early—before the ground becomes hard and difficult to work, before traffic has been compelled partially to do the work of the road leveler, and while the surface is in condition to unite with the loose earth left by the machine, and when the roots of grass and weeds do not interfere with the work of the blade. Unfortunately this work is often postponed until the ground is so hard that it is impossible to do a thoroughly good job. If the ground is a little too wet for tillage, it is all the better for road making, since it will pack and harden better than though it were drier. After the ground becomes dry and hard, it is not only more laborious and expensive to secure a smooth surface; but the newly repaired road may for weeks be in a worse condition than before it was worked, since the loose earth is too dry to pack under traffic.

211. A common error in scraping roads is not to begin far enough down in the ditch, thus leaving a shoulder which prevents the water from flowing from the roadway into the side ditch. Fig. 37 shows a

FIG. 37.—OBJECTIONABLE SHOULDERS LEFT BY SCRAPING GRADER.

road finished in this way. The shoulders not only dam back the water, but also narrow the roadway; and after weeds and grass have got a good start, it is improbable that the shoulder will be cut off next time the road is scraped, and in all probability each successive scraping will make a bad matter worse. However, with a skilful use of the scraping grader these shoulders can be cut off.

Not infrequently writers claim that material from the side ditches should not be placed upon the roadway. Unquestionably silt from the bottom of the ditches is undesirable material with which to built or repair a road; but in ditches properly constructed and cared for, there is not much, if any, of such material, and if any of it is removed with the scraping grader it is so thoroughly mixed with good material before it reaches the roadway as to be practically harmless. The advice against fine material from the side ditches originated when the drag scraper was the chief tool used in repairing roads, and the advice has unfortunately outlasted its usefulness.

212. *Cost with Scraping Grader.* The scraping grader may be drawn by three 2-horse teams or by a traction engine; but unless the roads are very hard and tough, horses are more economical than the tractor, since the grader is too small to be used economically with the ordinary tractor.

To shape up the road in the spring, six horses and three men are required to operate the scraper. The wages of a team and driver will usually be \$3.00 or \$3.50 per day, since generally the scraping should be done when farmers are busy with farm work, and since the work is hard on teams. The cost of operating the grader is then \$9.00 to \$10.50 per day. A scraper will on the average smooth up 3 or 4 miles per day, at an expense of \$3.00 to \$3.50 per mile, or, in round numbers, including repairs and loss by bad weather, say, \$4.00 per mile. If the road is not very rough, two rounds are enough; and if it is very bad four may be required, but usually three rounds are sufficient. If the work is postponed too long, the cost may be nearly double the above.

The cost of smoothing up city streets would be considerably more than the above, because of the time consumed in passing sidewalk crossings or in turning to avoid them. Particularly under such conditions, the amount of work accomplished in a day depends greatly upon the training of men and horses.

213. The V Road-Leveler. One form of this machine is shown in Fig. 38. It consists of two cutting blades 18 or 25 feet long, suspended from a platform which carries the operating machinery. The spread of the cutting blades and also the relative height of the two ends are adjustable. The machine is drawn behind a 15 to 25 H.P. tractor. With the longer blades the leveler will smooth up a maximum width of 30 feet at one time; and with the shorter blades 22 feet. Either size machine can shape up a roadway 10 or 12 feet wide. There are at least two other somewhat similar forms of this machine.

FIG. 38.—THE V ROAD-LEVELER.

The scraping grader is too large for a convenient number of horses, and too small for a tractor; and hence the V road-leveler was

invented to economically utilize the full power of an ordinary traction engine.

Sometimes three large adjustable steel road drags are hitched behind a traction engine, and do substantially the same work as a V road-leveler.

Sometimes a drag or a roller is hitched behind the V road-leveler, to level down or consolidate the loose earth left between the cutting blades.

214. Filling Holes. After the road has been smoothed by the scraping grader or the V road-leveler, it is a good plan, particularly if the road is very rough, to send a man with a shovel to fill up all ruts and depressions that were too deep to be filled by the scraper. If a deep hole has been filled by the scraper, it is well to add a little more earth to provide for settlement in order to prevent the reappearance of the hole. The new material should be trodden or tamped solidly into place.

Holes and ruts in an earth road should never be filled with stone, brick, or coarse gravel. The hard material does not wear uniformly with the rest of the road, but produces bumps and ridges, and usually results in making two holes, each larger than the original one. It is a bad practice to cut a gutter from a hole to drain it to the side of the road. Filling the hole is the proper course, whether it is dry or contains mud.

215. Removing Stones. All loose stones larger than 2 inches in diameter should be removed; and stones projecting above the surface should be dug out. They should be taken entirely away, or be piled beyond the side ditches; and should never be left just outside of the trackway, as is sometimes done, where they restrict traffic and obstruct the flow of water from the center of the side ditches.

216. Care of Side Ditches. The side ditches should be examined in the fall to see that they are free from dead weeds and grass; and late in the winter they should be examined again to see that they are not clogged with corn stalks, brush, etc., washed in from the fields. The mouth of culverts should also be cleared of rubbish, and the outlet of tile drains should be opened. Attention to side ditches will prevent overflow and washing of the road-bed, and will also prevent the formation of ponds at the roadside and the consequent saturation of the road-bed. The road care-taker should frequently go over his portion of the road just as a heavy fall of snow is going off, for it is then that water does most damage.

217. Care of Roadside. It is desirable that the roadside should be so cared for as to secure a coating of grass instead of unsightly and noxious weeds. This can usually be accomplished at a slight expense by an occasional mowing.

218. Care of Trees and Hedges. Earth roads should have plenty of light and air. Trees along the road may add beauty to the landscape (§ 195), but shade is nearly sure to breed mud holes. In some localities and under some conditions, shade upon the road surface should be eliminated by cutting down the trees or by trimming them so as not to keep the breeze and sunlight from the road; but in other localities and under other conditions, a little of the utility of the road may be sacrificed to secure attractiveness in the general surroundings.

A tall hedge cuts off the view of the adjacent country, shuts out the breeze, in a dry time keeps in the dust, and in a wet time retards the drying of the road. The hedges usually belong to the adjacent private property, but in most states the height is limited by statute; and in such cases the road officials should enforce the law. If there is no law governing hedges and trees near the road on private property, the road officials should use all possible diplomacy to have trees and hedges trimmed with reference to the benefits of the road. In this connection, see § 219.

219. Obstruction by Snow. In localities subject to heavy falls of snow, it is an important matter to keep the roads from becoming obstructed by it during the winter. In some countries where there is only an occasional fall of snow, as in France, it is customary to remove it from the surface of the road; but where there is much snow, it is only necessary to compact it so as to make the road passable. This is done by driving horses or cattle back and forth along the road, or by rolling the road with a heavy farm-roller. The use of the roller should commence with the first storm of the season and be continued as often as necessary through the winter. In the case of a very heavy storm, the roller should be sent over the roads at intervals during its continuance. Obviously this work must be done by the residents along the road.

Snow and ice frequently accumulate in the side ditches to such a height as to make the surface of the road the principal line of drainage. In the spring, when this occurs on earth roads, a large volume of snow-water flows down the road, and often seriously damages it by washing gullies in the surface. The best water-bound macadam roads may be seriously injured in this way; and in some localities

it is necessary to remove the snow from the side ditches to prevent damage of this character. The difficulty and expense of keeping the side ditches free from snow and ice is greatly increased if the ditches are deep and narrow, particularly since with this form of ditch it is necessary to maintain a culvert or covered gutter at the junction of cross roads and private drives with the main highway. These culverts are very liable to become clogged with icy snow, and it is nearly impossible to clear them without digging them up—which is rarely practicable. This difficulty could be obviated, or at least greatly decreased, by constructing shallow side ditches; and, if necessary, laying a large tile drain under the ditch to carry the surface water.

The cost of work occasioned by snow can be decreased by proper attention to the fences, underbrush, etc., along the side of the road. Snow drifts are caused by the obstruction of the currents of air near the ground—those that carry the drifting snow. In forests the winds do not have sufficient velocity to carry the snow, and consequently it lies evenly and of a uniform depth; but in the open country it drifts with the wind. Fences and shrubbery which retard the winds but permit the snow to blow through, cause the snow to pile up on the sheltered side and possibly to block the road and ditches. The fences should be either quite open or very close. A high tight fence obstructs the wind, and causes the snow to pile up on the windward side. If the roadside is partially obstructed, the wind moves the loose snow into earth cuts and also into the beaten snow path, and fills them up. Filling the snow trackway gradually raises the traveled portion of the road until turning out into the loose snow becomes dangerous.

220. In Vermont, "in many townships the cost of keeping the roads passable in the winter is one third, and in some one half, of the total amount expended on the highways, and the average for the state is one eighth," or $4.30 per mile per annum.

221. The possible cost of maintenance on account of snow should be considered in locating a road (§ 100–02).

222. Systems of Maintenance. The administration of the maintenance of earth roads is a matter of great difficulty. The difficulties are: 1. The justifiable expense is comparatively small; and hence the man who does the work must have charge of a considerable mileage, and consequently can get over the road only at infrequent intervals. 2. In many states the maintenance is done in whole or part by the labor tax, which at best is inefficient. 3. The

amount of work required may vary suddenly and greatly with local storms. 4. The administration is usually in the hands of an inexpert man or board to whom the care of the roads is only an incident in private or official duties. In this connection, see § 41.

As a rule inadequate attention has been given in this country to the maintenance of roads, and this is particularly true of earth roads. For the latter there have been only a few attempts to develop an efficient system, and even they are still in the experimental stage. Further, the conditions vary so greatly in different parts of the country that a system that is reasonably successful in one locality may be wholly inapplicable in another.

The various systems that have been attempted may be classified somewhat roughly as follows: (1) intermittent repairs; (2) continuous repairs; (3) continuous maintenance; and (4) contract system. These systems differ greatly and over-lap as applied in different localities.

223. Intermittent Repairs. This system is with propriety often called the pathmaster system. In this system the care of the roads is left to the official pathmaster, who has charge of 8 or 10 miles of roads, and who superintends the working out of the labor road-tax. This is the most common but least efficient system. This system has all the objections enumerated in § 222.

In practice this system is a method of intermittent repairs rather than maintenance, that is, under this system the roads are allowed to get into a comparatively bad condition before they are repaired or restored.

224. Continuous Repairs. This system consists in putting the care of the roads of a township or its corresponding administrative road-unit into the hands of a small squad of men who give all or substantially all of their time to the care of the roads. These men are provided with a scraping grader (§ 155) or a V road leveler (§ 213), and teams or a traction engine, shovels, picks, etc.

The theory of this system is that the roads, or at least the main ones, will not get very bad, or be bad very long, before the repair gang will be along. The advantages of this system are: (1) the squad is employed continuously, and hence becomes more expert; and (2) the amount of road cared for is so great as to warrant providing the squad with a good outfit. The disadvantages are: (1) the work is not done at the most advantageous time, i. e., when the soil is most easily worked; and (2) the roads are not in good condition all the time.

225. Continuous Maintenance. The essential feature of this system is that the care of a definite road is allotted to one man, who makes this his first business. The system is sometimes called the patrol system, and takes this name from the method long employed, chiefly in Europe, in caring for water-bound macadam roads in which a man devoted all of his time to patrolling and caring for a comparatively short piece of road.

It is not usual to attempt formally to maintain any but the most traveled earth roads. Even on these roads the amount of work required varies so much with the season and with the frequency of storms, that the section must be comparatively short; and therefore at times there is not work enough to require the full time of the patrol. To meet this condition it is customary to employ a man who lives near the road, to labor upon the road when directed. The direction of the patrols is in the hands of a township official or foreman; and a general supervision of all the foremen is in the hands of the county engineer.

The only work ordinarily attempted is to drag the road as needed. The overseer or superintendent communicates with the patrols by telephone, both to inquire as to the condition of the roads and to order work done. The patrol is usually required to report by postal card as to the work done and the time required. In some cases a report is required for each day's work, but sometimes only a weekly report is demanded. In some states a portion of the road tax is set apart by statute to pay for dragging, and can not be used for any other purpose.

The length of the sections vary with the possibility of securing competent patrols; but are preferably not more than a mile or two each, so as not to interfere too much with the other duties of the patrol.

Prizes are sometimes given for the best work, the money for the same in some cases being taken from the road taxes and in other cases is contributed by Chambers of Commerce, etc.

By this system of maintenance the roads are kept all the time in a fairly good condition. In a number of cases where tried the conclusion reached was that the condition of the roads was much better under this than under other systems, and at the same time the total cost was less.*

226. In those states in which an attempt is made to continuously

* For one example, see *Engineering Record*, Vol. 73 (1916), p. 643–44; and for another see *Engineering and Contracting*, Vol. 38 (1912), p. 714.

maintain the earth roads, there is usually a law prohibiting the use of the dragged surface until it has dried out so that a wheel will not make a rut.

227. Maintenance by Contract. In view of the ordinarily inefficient system of caring for roads, it has frequently been proposed to maintain them by contract. As a rule, work done under the supervision of a contractor who has pecuniary interest in the result is more economical than that performed under the direction of a public official; but it is not wise to do work by contract unless the amount required can be approximately known beforehand, and also unless the character of the performance can be easily determined after completion. Neither of these important conditions would be present in a contract for the maintenance of a public highway. Owing to the indefiniteness as to the amount and character of the work to be done, it is not at all certain that the maintenance could be provided for by contract for a sum less than the public officials could do the work under the present system. The inspection would finally depend upon the road official, and the letting of a contract would increase the difficulties and expense of supervision.

It is claimed that the contractor could maintain a trained corps, and therefore do better work than can be done by the present system; but it is doubtful if contract work would be any cheaper or better than the method described in § 225.

228. Expenditures for Maintenance. There are but few data concerning cost of maintaining earth roads, and much of that is very indefinite since the conditions of soil, weather, etc., are not stated and also since no definite information can be stated as to the quality of the maintenance.

229. Dragging. The cost of systematically dragging a road in Arkansas was $11 per mile per annum, or 50 cents for each dragging.*

In Tennessee 30 miles of roads in sections of 3 miles each were dragged during the months of December, January, February, and March, under the continuous maintenance system. The price for a man and a 2-horse team was 30 cents per hour. The county furnished the drags. Prizes were offered for the best kept road, and the prize was awarded to a road for which the cost was $5.00 per mile per annum.

In Hale Township, Carroll County, Missouri, an overseer is in charge of every 8 miles of road, and has ten patrols, each in charge of a section. After each rain the overseer by telephone calls upon the

* Bul. No. 48 of the U. S. Office of Public Roads, p. 46–7.

patrols to drag the roads. The cost of maintaining the roads during April, May and June is from $10 to $15 per mile, including $15 for each overseer.

Clayton County, Iowa, from 1913 to 1916 maintained the county roads, i. e., 226 of the 1350 miles in the county, by the continuous maintenance system. The patrol section was from 7 to 10 miles. Some of the patrolmen put in all their time, but some only part time. The patrolmen hired help as was necessary. Each patrolman furnished his own team and wagon. Usually three horses were used on a drag. The average pay was $27\frac{1}{2}$ cents per hour for patrolmen, $47\frac{1}{2}$ cents per hour for man and team, and 10 cents per hour for each extra horse. Patrolmen's assistants were paid 25 cents per hour, and 45 cents per hour for man and team. The average cost of dragging was $56\frac{1}{2}$ cents per mile for one round trip. The total cost for maintenance and repairs averaged about $56 per mile per year. The average cost of dragging in Clayton County was $56\frac{1}{2}$ cents per mile per round trip; while that in other counties of the state was 71.3 cents per mile per round trip.*

230. Total Cost of Maintenance. The following data are for the maintenance of 70 miles of road during the years 1909 and 1910 in northern Michigan.† The roads were maintained by the patrol system under the direction of the County Engineer. The roads were "floated," i. e., dragged with the slicker or lapped-plank drag, once when the frost was partly out and once after it was completely out. The roads were dragged after every heavy or protracted rain during the season. After the roads had settled in the spring, every hole was filled, and the roads otherwise put into good condition. The patrols were required to be on the road and work upon either the road-bed or the drainage system, two specified days in each month. They were expected to mow weeds and brush on the roadsides, break through the snow in winter, and keep the road to the standard of a good earth road. The cost was as shown in the tabular statement on the opposite page.

"The greater cost of dragging in 1909 was because the roads had not previously been dragged; and the greater cost of general repairs in 1910 was because of the higher standard of maintenance." ‡

231. Table 20, page 132, gives the results of a test in maintenance

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* *Engineering Record*, Vol. 73 (1916), p. 643.

† K. I. Sawyer, in Proc. 1915 Short Course in Highway Engineering, University of Michigan, p. 62–64.

‡ Private letter from Mr. Sawyer.

conducted by the U. S. Office of Public Roads.* "Before the maintenance was undertaken the county repaired the road and put it in good shape. The repairs consisted in shaping parts of the road with a scraping grader, clearing and widening the ditches and clearing the culverts, and applying gravel to a section of the road. The cost

	1909	1910
Length maintained, miles	70.5	72.5
Length of patrol section, miles	6	4–6
Average cost, per mile:		
Dragging	$26.17	$8.65
Patching surface, culvert and ditch work, cutting weeds and brush	8.56	19.77
Total cost per mile	$34.73	$28.42
Cost of dragging one mile one time	.....	0.925

of the repairs was $700. On the 8 miles of road there are 4 bridges, 19 culverts, 54 drain pipes under driveways, 59 intersecting roads with drain pipes, 42 intersecting roads without drain pipes, and 10 small wooden bridges across the gutter. The entire 8 miles of road is well traveled, and there is considerable heavy teaming over parts of it A portion of the road is also used by United States cavalry. There is also considerable automobile traffic on some portions. A travel census for 3 days in March on one section of the road shows the following: Loaded 1-horse wagons, 15; unloaded 1-horse wagons, 58; loaded 2-horse wagons, 38; unloaded 2-horse wagons, 49; loaded 4-horse wagons, 9; unloaded 4-horse wagons, 4; saddle horses, 96; and motor runabouts, 1. The patrolman furnished a horse, cart, and small tools. He was supplied with a plank road-drag, and required to furnish two horses to drag the road whenever it was in suitable condition for dragging, usually following each rain. He was paid $60 per month and $1.00 per day extra whenever he used two horses to drag the road. His presence was required on the road from 8 a.m. to 4:30 p.m., with thirty minutes allowed for lunch."

"The cost of dragging was approximately $1.25 per mile for each dragging of three round trips. The item of $169.88 for repairing, clearing and improving ditches and underdrains was large, because it was found necessary as the year progressed to rebuild entirely portions of the gutters and ditches.

* *Engineering and Contracting*. Vol. 38 (1912), p. 714.

TABLE 20

COST OF MAINTENANCE OF 8 MILES OF ROAD IN ALEXANDRIA COUNTY, VIRGINIA, From December 17, 1911, to June 30, 1912

Ref. No.	Kind of Work.	Days.		Cost.	
		Total.	Per Cent.	Total.	Per Mile.
1	Dragging	38.5	22.7	$128.89	$16.11
2	Repairing, cleaning and improving ditches and underdrains	73.	42.9	169.88	21.22
3	Cutting brush, etc	26.5	15.6	61.78	7.72
4	Picking off stones	10.5	6.2	24.55	3.06
5	Taking census	10.	5.9	23.36	2.92
6	Inspection during storms	5.5	3.2	12.67	1.58
7	Clearing fallen trees, building guard rails, etc	6.	3.5	13.86	1.73
	Total for 6.5 months	170.00	100.0	$434.99	$54.34

"The following conclusions are clearly demonstrated by the experiment: (1) The use of the drag has greatly improved the daily condition of the road and rendered it smooth and comfortable for travel for a greatly increased number of days in bad weather. (2) A width of earth road in excess of 24 feet is unnecessarily expensive to maintain. (3) The presence of the patrolman during storms and immediately after, saves considerable expense for repairs due to the wash of surface water. (4) The existence of poorly drained private driveways and intersecting roads is a constant expense for maintenance. (5) The use of small tiles for side drains and the building of wooden bridges over gutters at driveways is a serious obstacle to proper drainage. The pipe is usually laid at insufficient depth, and becomes broken and clogged. It would appear that paved gutters at driveways would not be unduly expensive in the long run, and would certainly provide better surface drainage. (6) It is not economical to employ a patrolman during the winter months, unless his time can be used to advantage in clearing brush and rubbish from the right-of-way; but a man should be constantly in charge of every mile of road to inspect it during storms, and to free the ditches. (7) The presence of old cobble stones and poorly consolidated coarse gravel is a serious impediment to the use of the drag. The stones must be removed from the road before dragging can be successful. (8) There is ample work for one man continuously during 8 or 9 months of the year; and there is difficulty in combining road-patrol work with the dragging of earth roads."

232. Table 21 gives details of the average annual expenses for roads in Champaign County, Illinois. Notice that part of the expenditures are for maintenance proper, while part are for improvements in the original construction.

TABLE 21

AVERAGE EXPENDITURES PER MILE OF EARTH ROADS IN CHAMPAIGN CO., ILL.

1. New steel bridges—exclusive of county aid *	$16.20
2. Drainage	6.32
3. Tile culverts	1.32
4. Repairs of bridges and culverts	2.93
5. Grading (not simply smoothing and leveling)	1.43
6. Smoothing and leveling (not grading)	2.83
7. Mowing the roadsides	1.14
8. Administration	2.69
Total average annual expenditure	$34.86

It is not known that any data similar to those in Table 21 were ever before collected, and hence there is no means of knowing whether these data are representative. These expenditures were in 1900 before the use of oil in maintaining earth roads (see Art. 3 of this chapter). It is probable that the expenditure for bridges is considerably larger than the average. Champaign County is rolling prairie situated in the corn belt. There are no large streams, and practically all the land is under cultivation. Farm lands without buildings then sold at $80 to $100 per acre. There are 1.97 miles of road per square mile of area outside of cities and villages. All the roads have a black loam surface.

ART. 3. SURFACE OILING

233. The surface of an earth road is sometimes treated with oil to prevent dust and also to aid in keeping the surface smooth. In small towns and villages the former is the chief purpose; while on rural roads the latter is the main, or sole, object.

234. PREVENTING DUST. The annoyance from dust usually reaches its maximum in small towns and villages, owing to the concentrated travel and the presence of more people to be inconvenienced. The dust can be greatly reduced by properly dragging the road. The surface should never be dragged when dry, since the

* In Illinois the county pays half the expenses of bridges costing more than a specified per cent of the assessed value of the township. The expenditures by the county for new steel bridges is nearly as much as by the township.

resulting loose earth will speedily be ground into dust; and for the same reason, an excess of loose earth should not be left in the center of the road.

Within the last decade many dust palliatives and preventatives have been used; but oil is the agent most frequently employed on earth roads. Crude tar has been employed as a dust palliative; but on account of its injury to rubber tires and also on account of its tracking into houses, it is not satisfactory.

235. Effect of Oil on Maintenance. Loam and clay roads are improved by a little moisture—just enough to keep them damp and dark without making them soft or spongy. In dry climates the roads not only become excessively dusty, which is a great discomfort, but also wear into pot-holes, which are dangerous, since being filled level-full of dust their presence is not revealed until a wheel or a horse's foot plunges into them. In some localities the dust at times is practically hub deep, and is not only an annoyance but greatly increases the tractive resistance. In arid climates and even in dry times in humid climates, sprinkling with water is an effective means of maintenance. A layer of straw is sometimes put upon the road to subdue or prevent the dust; but of course the effect is only temporary.

Recently crude petroleum has been employed on highways, instead of water, to prevent dust. Oil has been used for this purpose in Southern California more than elsewhere, primarily on account of the high grade of oil that is available at low cost, but also on account of the sandy soil, the semi-arid climate, and the absence of freezing weather.

Oil when applied to loam and clay roads, reduces the dust, makes the road-bed at least partially non-absorbent, and gives a dark-colored surface which is more pleasing to the eye than the ordinary light, dusty soil. Since the road-bed is less absorbent, it is not so easily worked into mud; and besides the oily surface more readily sheds the rain water into the side ditches. In localities where there is frequent thawing and freezing and also much rain, the effect of oil on loam and clay roads does not last through the succeeding winter, except in case of an unusually dry winter and spring. In comparatively dry climates and upon a sandy soil, the continued application of suitable oil to the surface tends to gradually improve the condition of the road-bed. However, whatever the character of the soil, roads having a considerable hauling are not materially improved either temporarily or permanently.

236. Preparing the Surface. The surface should be smooth and properly crowned, so as to shed water into the side ditches. The surface can be properly prepared with a road drag (§ 206) or a scraping grader (§ 155), according to the degree of roughness and the dryness of the soil. If much earth is moved in shaping the surface, the road should be subjected to travel to consolidate the loose earth; and if depressions appear these should be filled, and be consolidated by travel or other means before the oil is applied. The expense incurred in securing a hard, smooth, properly crowned surface will more than be made up by the increased effectiveness of the oil treatment. For the best results the upper 2 inches of the road should be fairly dry; but the surface should be free from dust.

237. The Oil. For a discussion of the origin and character of road oils, the method of shipping them, and specifications for oils suitable for the different kinds of soil, see Art. 2 of Chapter VIII.

238. Applying the Oil. The oil should be applied at the rate of one fourth to one half gallon per square yard of surface. If the road has never been oiled, or if more than one season has elapsed since a previous oiling, about a half gallon per square yard will be required. If the road has been oiled earlier in the season, one fourth to one third of a gallon per square yard will usually be satisfactory. It is much better to apply a small amount of oil twice each season rather than to put on the full quantity in one application. When too much oil is applied, it is not only wasted, but is often disagreeable to the users of the road. The first time the road is oiled, the best results may be secured by using a thin product that will penetrate the road-bed to a considerable distance and at the same time contain as much binding material as possible. The oil should be thin at ordinary atmospheric temperatures, and applied cold. If a thick oil is used for the first application, it will not penetrate to any considerable distance, but will form a mat upon the surface; and consequently, if the road is not well underdrained, the accumulation of moisture under the mat may cause the road to dry out more slowly, and may also cause the mat to break up. After the top layer of the road has been saturated, a heavier oil may then be used; and it is best applied when hot.

239. The uniform distribution of the oil is one of the essential requirements for success. An ordinary street sprinkler or a home-made device attached to a thresher tank-wagon may be utilized for distributing the oil, although considerable care is required to

secure the right amount and a uniform distribution. Much better results can be secured by the use of specially designed pressure distributor tank wagons or trucks. There are a number of such wagons and trucks on the market. Some of them are equipped with a heating device so that hot oil may be applied when required; and all have pumps for distributing the oil uniformly and under pressure, and some have a device for spraying the oil upon the road.

On earth roads the use of the pressure distributor is useful mainly to secure the proper quantity; but on a gravel or broken-stone road the pressure distributor is important, since applying the oil with force blows the dust off the pebbles or stones and permits a better adhesion of the oil. The chief advantage of the spray is that it secures a more uniform distribution.

The distributor should be so regulated that the width to be oiled will be covered by one or more uniform strips without any overlapping. Any spots between the strips that are not covered by the machine distributor, should be covered with a hand-pouring can following immediately after the distributor. For the best results the oil should be applied in two equal coats with an interval of at least 5 or 6 hours between them to allow the first to be absorbed before the second is applied. Travel should be barred from the road for 3 days after the first coat is applied, to allow the oil to be absorbed.

Fig. 39 shows a pressure tank wagon for distributing road oil. This road oiling-machine is provided with an oil-burning heater and a jacket around the tank; and also has two pumps for applying the oil under pressure and regulating the amount. Fig. 40 shows another form of road oiler.

240. Cost of Oiling. The cost of preparing an earth road for oiling will vary greatly, depending upon the condition of the surface. If the surface is not already well crowned, the road should be treated with either the road drag or the scraping grader. However, such work should not be considered as part of the cost of oiling; but should be considered as part of the cost of construction or of maintenance, since the road should be properly crowned and be kept so whether or not it is oiled. Even though the surface is properly maintained, it will probably be necessary to drag the road and otherwise shape it up; and this cost may be $10 to $25 per mile.

The price of oil for earth roads varies from 4 to 8 cents per gallon (§ 560–61). The oil is usually applied at the rate of $\frac{1}{4}$ to $\frac{1}{2}$ gallon per square yard, and the oiled width is generally 15 feet; and

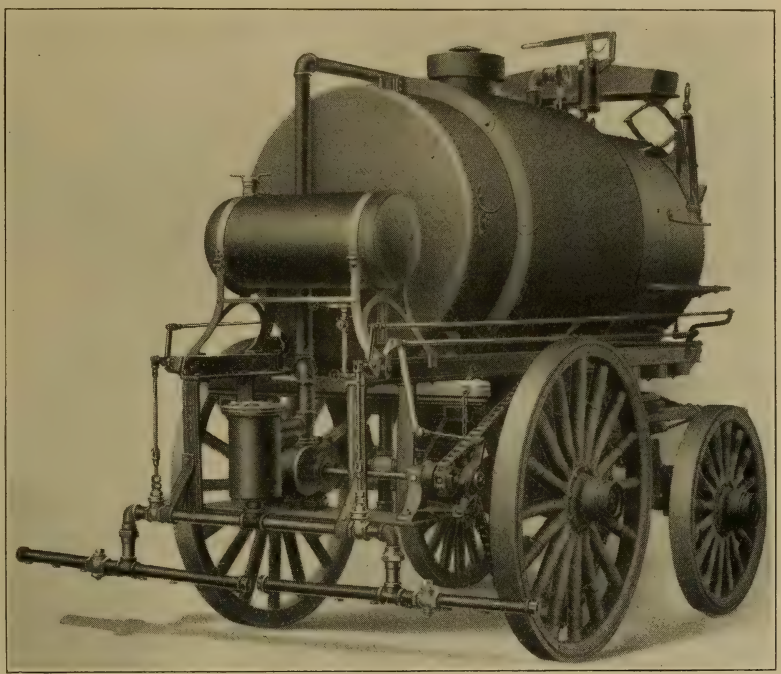

FIG. 39.—ROAD OILING-MACHINE.

FIG. 40.—MACHINE APPLYING ASPHALT OIL.

therefore with the smaller values above, the oil may cost $88 per mile, and with the larger values $352.

The cost of applying the oil will depend upon the length of the haul, the size of the tank, and the method of applying; and may vary from $50 to $150 per mile for machine application. Therefore, the total cost of oiling, including only slight preparation of the road surface, and excluding rent and depreciation of equipment, and also excluding general administrative expense, will vary from $148 to $527 per mile.

CHAPTER IV

SAND AND SAND-CLAY ROADS

Art. 1. Sand Roads

243. As a rule roads on pure sand are the worst in existence, since they are good only when wet, and therefore are at their worst most of the year; while in most localities clay or loam roads are at their best most of the time. If the sand is fine, a dry sand road is worse than any muddy road.

244. Drainage. Roads on pure or nearly pure sand require very different treatment from those on clay and loam. Dampness improves a sand road, while it damages a clay or loam road; and therefore the preceding rules for the drainage of loam or clay roads must be reversed for sand roads. Wet sand makes a better road than dry sand, and therefore draining a sand road is useless and possibly a damage. Of course, this is not true of quicksand, since that is improved by drainage; but there is very little, if any, of this material in roads.

245. Grading. Sand roads are usually nearly level longitudinally; and hence need little, if any, grading. They should not be crowned, since they do not need surface drainage. The traveled portion should be simply leveled off.

246. Shade. While shade harms a loam or clay road, it improves a road of sand or broken stone, since it prevents the evaporation of the moisture from the road-bed. Therefore a sand road can be permanently improved by planting trees so as to shade the traveled way. They will prevent, in part, the drying effect of the winds, as well as intercept the rays of the sun.

247. Hardening the Surface. The great disadvantage of pure sand as a road material is the freedom with which the grains move one on the other; and therefore to improve a sand road grass should be encouraged to occupy all the space possible, since its roots will decrease the movement of the grains under the tread of the

hoofs and wheels. It is an advantage if low growing bushy vegetation occupies the surface clear up to the traveled way—both for the shade and for the binding effect of the roots and the leaves. The leaves fall into the ruts and also aid in binding the sand.

Where no other recourse is possible, it is advantageous to have two roadways adjacent to each other, one of which is planted with grass while the other is in use. If the traffic is not very great, the effect of the grass will last for a year or two after the road is again used by the wheels. A fertilizer is sometimes applied to stimulate a growth of grass upon the wheelway. In some localities the sand is so fine that it drifts like snow, and fills the partially hardened way, in which case the road is improved by planting the roadsides with grass to prevent the sand from being blown into the road.

A road on pure sand is improved temporarily by covering it with a thin layer of any vegetable fiber, as decaying leaves, straw, marsh hay, waste from sorghum mills (bagasse), fibrous or string-like shavings, etc. This fibrous material soon becomes incorporated with the sand and decreases its mobility; but the vegetable matter wears out and decays, and consequently the effect is only temporary. The length of time such expedients will last depends upon the climate and the amount of travel.

248. In this connection it is a significant fact that the sand shoulders of a broken-stone road soon become firm and hard, owing to the infiltration of the fine dirt and stone dust washed from the surface of the roadway. The fine particles of dust between the grains of sand act mechanically to decrease the mobility of the sand, and to increase capillary attraction and diminish percolation, which in turn keeps the sand damp and still further decreases its mobility. Apparently, then, the incorporation of fine dust in a sand road will improve it; but it will be difficult to procure sufficient dust for this purpose.

Art. 2. Sand-Clay Roads

250. A sand road is best when wet, and a clay road is worst when wet; but a road surface constructed of sand and clay mixed in proper proportions possesses the good qualities of both the sand and the clay, and frequently is better then either. Such roads are called sand-clay roads, and give the best results where the ground is not subject to deep freezing. Materials suitable for the construction of sand-clay roads are found in greater abundance in the southern states than in

any other portion of this country; and consequently sand-clay roads are much more common in that portion of the country, although sand-clay roads have been built to a considerable extent in several northern states. There are many localities, particularly in the South, where sand-clay roads are the only improved roads which are economically possible. In many cases a sand-clay road gives good service at comparatively low cost of both construction and maintenance.

Three distinct methods are employed in constructing sand-clay roads, viz.: (1) a natural mixture of sand and clay is placed on top of either a sand or a clay road; (2) a layer of sand is incorporated in the road-bed of a clay road; or (3) a layer of clay is added to a sand road.

251. THE DESIGN. The width and thickness adopted will of course depend upon the travel and upon the money available. For a single track the improved width is usually 10 or 12 feet, and for a double track 14 or 16 feet. For a discussion of the super-elevation and width on curves, see § 90 and 97, respectively.

The thickness at the center varies from 6 to 10 inches, usually 6 to 8; and at the sides 4 to 8, usually 4 to 6, but feathers out at the very edge. The crown should be $\frac{1}{2}$ to $\frac{3}{4}$ inch per foot of total width.

252. NATURAL MIXTURES OF SAND AND CLAY. Sometimes a natural mixture of sand and clay is found in such proportions as to make an excellent road surface for moderate travel under most or all weather conditions.

The next chapter treats of gravel roads, and a special case of a gravel road is one in which a layer of natural cementing gravel is added to a clay or loam road; but such a form of construction will not be considered here.

253. To Test the Sand-Clay Mixture. To determine the probable wearing power of natural mixtures of sand and clay proceed as follows:

1. Examine the existing road to see if there are any portions that are reasonably good under all weather conditions, to identify the character of soil desired for other portions of the road.

2. Observe out-crops of sandy clay or clayey sand. The best mixtures of sand and clay for road building purposes will stand at relatively steep slopes, will develop few surface cracks in drying, and will appear dense and firm in dry weather.

3. Determine the percentage of clay and sand in the mixture. To do this, thoroughly dry a sample of the soil, weigh it, place it in

a vessel several times larger than the sample, fill the vessel with water, agitate the water, and pour off the muddy water. Before pouring off the water, allow it to stand a minute or two, so the sand may settle and thus prevent its being carried away with the clay. Repeat the washing until the water remains clear; and then dry the sand and weigh it. Fair results may be expected if the sand content is from 50 to 70 per cent; but the best results are obtained when the sand varies from 60 to 70 per cent; or in other words, for the best results about two thirds of the mixture should be sand. Further, the greater the proportion of coarse to fine sand the better.*

4. Sometimes a natural mixture may be improved by combining it with another natural mixture or with nearly pure clay or pure sand. A determination of the sand and clay contents of the natural mixture will give some indication of the element needed to improve it; but the only way to determine it definitely is to make several trial proportions and test them. To determine which of several natural or artificial mixtures will probably give the best results in the road, proceed as follows: Mix the sample to a stiff mortar; spread a small quantity of each mixture upon a board or plate of glass to the thickness of about 1 inch; and with some improvised equivalent of a biscuit cutter, cut from each mixture two samples containing 1 to 2 cubic inches each. It is essential to cut only equal quantities from each mixture. Roll these samples between the palms of the hands into approximately true spheres; scratch a number on each; and then place them in the sun to dry. When thoroughly dried, one sphere of each sample should be tested dry and the other wet. To test a sphere dry, rub it lightly with the thumb, and if it has too much sand it will disintegrate rapidly; while if it contains an excess of clay, it will speedily rub into dust. If it has a suitable proportion of sand and clay, it will simply become slightly glazed, and will offer considerable resistance to abrasion. To test the spheres wet, place them in a circle in a flat pan or dish, and gently pour enough water into the pan to cover them, being careful not to pour water directly upon any sphere. The specimens containing too much sand will break down first; those having an excess of clay will usually disintegrate next; and those having the best proportions will endure longest. These experiments will indicate the least

* For a series of complete sieve analyses of fourteen samples of material from sand-clay roads that had given good service, and a discussion of the relative merits of the same, see Trans. Amer. Soc. of Civil Eng'rs, Vol. 77 (1914), p. 1465–75.

desirable mixtures, and will also show what other proportions should be tested. A second test of the most promising mixtures will probably indicate whether or not any of the samples are worthy of a trial in an experimental section of road.

254. By proceeding as described above one may determine within comparatively narrow limits the possibility of successfully using any available mixtures of sand and clay for a road surface.

255. Construction. When a suitable mixture of sand and clay is available, it is only necessary to add a layer of this material to a sand road or to a clay road. The road-bed on clay should be underdrained and crowned as described in Art. 1 of Chapter III, and the surface of the sand road should be prepared as stated in Art. 1 of this chapter. The amount of the initial crown will depend upon the thickness of sand and clay to be added.

The sand-clay mixture is spread upon the road to the desired width and thickness (§ 251), and is smoothed with a scraping grader (§ 155) or drag (§ 206). Travel may then be admitted; but the road should not be considered finished until it has been thoroughly soaked by rains, harrowed to break up lumps, and again shaped with the scraping grader or drag.

After the road has been in service for a considerable time, if it develops that either clay or sand is lacking in the surface, a thin layer of that element may be spread and be incorporated into the road-bed with a disk or toothed harrow.

Finally the sand-clay road, if properly built, will become smooth, nearly dustless, and resilient; and under moderate travel should continue so without much, if any, expense for maintenance.

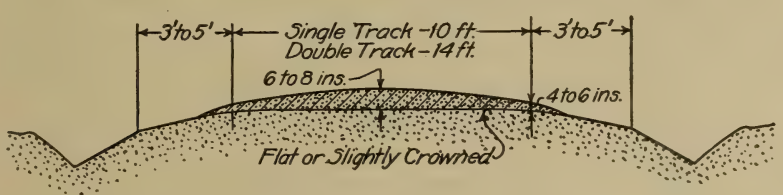

FIG. 41.—MIXTURE OF SAND AND CLAY ON NATIVE SUBGRADE.

256. SAND ON CLAY SUBGRADE. The object in this form of construction is to incorporate sufficient sand with the clay subgrade to obtain a mixture of sand and clay that will fulfill the conditions stated in § 253. For the best results the amount of clay in the finished road surface should not much exceed the amount required to

fill the voids in the sand. Ordinarily about two parts of sand to one part of clay gives satisfactory results.

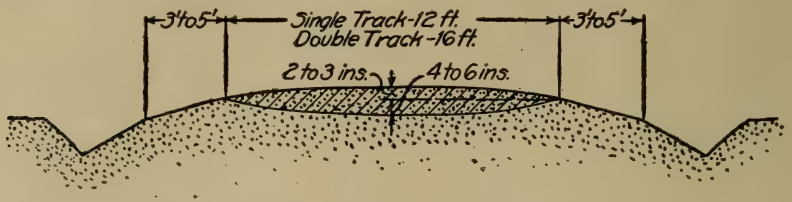

FIG. 42.—CLAY ON SAND SUBGRADE.

257. The Sand. The sand to be added to a clay subgrade should preferably be a coarse-grained pure silica sand. Any sand containing any considerable percentage of mica is not desirable.

For the best results, not less than 45 per cent nor more then 60 per cent of the sand should be finer than that caught on a standard No. 10 sieve, and coarser than that caught on a No. 60 sieve; and that caught on No. 20, 40 and 60 sieves should be about equal to each other.

258. The Proportions. The proportions of sand and clay can be determined approximately by finding the amount of water that can be poured into a vessel full of sand. To do this determine the weight of water required to fill any suitable vessel; and then fill the vessel with sand. Next determine the weight of water that can be poured into the vesselful of sand. For example, if the pail holds 12.4 lb. of water, and 3.5 lb. of water can be poured into the pailful of sand, then the voids in the sand are: $3.5 \div 12.4 = 28$ per cent. Therefore in the finished road the proportion of clay should be about 28 per cent, and that of sand about 72 per cent. This proportion and others differing slightly therefrom should be tested by the method described in paragraph 4 of § 253.

However, since exact mathematical proportions are not possible in incorporating the sand with the clay in the road surface, mathematical refinement in these experiments is inappropriate.

259. The Thickness. For average rural-road travel, the depth of the sand-clay surface should be about 6 to 8 inches at the center and 4 to 6 inches at the edges of the traveled way feathering out on the shoulders; and hence the thickness of the layer of sand to be added to the road should be roughly two thirds of the above depth, the exact thickness depending upon the best proportion of sand and clay as determined by the method described in § 253.

260. Construction. The surface of the clay road is shaped up as described for an earth road (§ 129–31), and is then thoroughly plowed to a depth of 6 or 8 inches according to the thickness of sand to be added. Next the thickness of sand determined as above is spread upon the surface and leveled down with the scraping grader or the road drag. The road is then plowed again, as deep as possible, to mix the clay and the sand; and after this plowing the sand and clay are further mixed by harrowing with a disk harrow, which can be done best when the road is wet. Attempting to mix the materials dry is usually unsuccessful. After the sand and clay are thoroughly mixed, the surface is smoothed and crowned with the blade grader or the road drag, and travel is admitted to complete the mixing and to compact the road. While the road is new it should be watched carefully, and the surface should be kept free from ruts and saucer-like depressions by going over it when necessary with the scraping grader or the V road leveler. When the road has begun to solidify, the road drag is not very effective—at least neither the split-log nor the plank drag. It will likely be necessary to add clay in spots where the road surface is loose, and sand where it is sticky. Probably the road will not arrive at its best condition for a year or two or at least not until after several long-continued wet spells during which the travel will thoroughly consolidate the road.

261. Clay on Sand Subgrade. The clay is added to serve as a binder to hold the grains of sand together. For the form of construction under consideration here, clay is the only material available for permanent effect. For the proportions of clay and sand to be attained, see § 253.

262. The Clay. Clay varies more in its suitability for road building purposes than sand; and it is difficult to determine in advance the result of a service test in the road.

All clays contain more or less sand, and as the clay is to serve as a binder for the sand, the less sand the clay contains, that is the more nearly it is a pure clay, the better; and hence loam, which is a mixture of clay, sand, and vegetable matter, is not the most suitable for this purpose.

The less the clay is affected by the presence of water the better. Clays are known as slaking and non-slaking. The former absorb water freely and slake or fall to pieces when put into water, somewhat like a piece of quick-lime; and are deficient in binding power, and hence are undesirable as a binder for a sand-clay road.

To compare the slaking qualities of several clays, make small

balls of each of approximately the same size by rolling between the hands, leave the balls in the sun or put them into an oven until they are well dried out, and then place them under water. The ball which holds its shape longest has the highest resistance to slaking, and contains the clay most suitable for use as binder in a sand-clay road. To make a fairly trustworthy comparison the samples should contain substantially the same proportion of sand; and therefore the percentage of sand in each sample of clay should be determined (see § 253) before beginning the above test, and sand should be added so as to give all samples the same proportion of sand.

The above method of testing may be employed also to determine the slaking qualities of the clay when mixed with different proportions of sand, and therefore may afford valuable information in fixing the proportions of clay and sand to be used in the road surface.

Other things being equal, the clay which shrinks least in drying out is best suited for use in a road surface. The relative shrinkage may be determined by observing the balls used in the test above, while they are being dried out before being immersed.

263. The Construction. The road-bed should be provided with side ditches and be graded as described for earth roads (§ 129–31), except that the surface should have but little, if any, crown. Then spread a layer of clay of such thickness that when thoroughly mixed with the sand of the road-bed, the mixture will have the required depth,—6 or 8 inches as the case may be. The thickness of the loose clay required will usually be a little greater than one third of the ultimate thickness of the combined sand and clay. The exact proportion of clay to secure this condition is to be determined as described in § 253.

After the clay has been spread and leveled off with a road drag, the clay and the sand are to be thoroughly mixed by successively plowing and then harrowing with a disk harrow. Roughly the plowing should extend into the sand to twice the depth of the layer of clay added. It is better at first to have too little sand rather than too much, for it is easier to correct the proportions by adding sand from the subgrade then by hauling clay from a distance. When the sand and clay have been thoroughly mixed in the correct proportion, the road should be properly shaped by the use of a scraping grader or road drag, and then travel may be permitted. After the first soaking rain, plow and harrow the surface again until the surfacing material practically becomes mud, after which shape up

the surface and keep it in shape by repeated dragging until it has dried out and is thoroughly compacted. At this stage the road roller should not be used, since it will harden only the surface and prevent the travel from consolidating the mixture from top to bottom. The crust formed by the roller will carry the travel until the first wet spell, and then it will cut through and the road will break up; and nothing permanent will have been gained by the use of the roller.

The road should be watched carefully for several months, and ruts and other depressions should be filled by the use of the steel road drag or the scraping grader. Any deficiencies in sand or clay that are revealed should be corrected by adding the lacking ingredient.

264. COST. In the Southern states the cost of constructing a

TABLE 22

COST OF SAND CLAY ROADS*

Exclusive of grading and materials

Items.	Mixture of Clay and Sand.		Sand on Clay Subgrade.		Clay on Sand Subgrade.			
	Brookville, Fla.	Gray Head, Miss.	Moscow, Miss.	Jackson, N. C.	Pearshall, Tex.	San Antonio, Tex.	Tarboro, N. C.	Sayre, Okla.
Length surfaced, miles	0.45	2.19	0.78	0.45	0.79	1.00	2.50	0.75
Width graded, feet:								
Cuts	28	22	30	30	26	40	22	28
Fills	20	22	30	30	26	26	22	28
Width surfaced, feet	16	16	17	14	15	16	18	14
Materials:								
Sand, cu. yd	660	1 700	1 524	890	.....	.....	.....	.....
Distance hauled, miles	0.75	0.125	1.5	1.00	.....	.....	.....	.....
Depth applied, inches	3	6	7	7	.....	.....	.....	.....
Clay, cu. yd	830	2 300	.....	.....	1 556	1 815	2 815	1 383
Distance hauled, miles	0.50	0.10	.....	.....	0.19	0.057	.....	1.42
Depth applied, inches	7	6	.....	.....	8	7	6	8
Wages per hour:								
Laborers	$0.175	$0.20	$0.10	$0.125	$0.12	$0.15	$0.08	$0.16
Teams	.50	.50	.25	.35	.30	.345	.24	.30
Cost:								
Subgrade, per sq. yd	.031	.....	.003	.002	.0064	.0088	.0018	.0096
Stripping surfacing material, per sq. yd	.....	.010	.....	0.29	.091	.072	.005	.134
Hauling sand, per sq. yd	.425	.223	.49	.84	.....	.....	.....	.....
Hauling clay, per sq. yd	.374	.344	.....	.....	.914	} .286	.255	.567
Spreading material, per sq. yd	.019	.003	.007	.077	.032		.0178	.072
Mixing sand and clay, per sq. yd	.0035	.010	.006	.....	.0017	.0069	.0024	.007
Final shaping, per sq. yd	.0035	.004	.....	.002	.0005	.0015	.0022	.....
General expense, per sq. yd	.0157	.006	.....	.003	.003	.....	.0007	.....
Total cost, per sq. yd	0.198	0.082	0.105	0.233	.121	.089	.036	.187

* Constructed by U. S. Office of Public Roads and Rural Engineering, Bul. No. 463 (1917), p. 45.

16-foot sand-clay surface, exclusive of grading, usually ranges between $500 and $1500 per mile and nearly proportionally for other widths. For details of the cost of some such roads, see Table 22.

In Michigan, which state seems to have more sand-clay roads than any other state except Georgia, the cost of a well-built 9-foot sand-clay road consisting of 6 inches of clay on a sand subgrade ranges from $1,000 to $1,800 per mile.

265. MAINTENANCE. The sand-clay road is really a superior type of earth road; and therefore all that has been said in Chapter III concerning the maintenance of earth roads applies also the sand-clay surfaces. As in the case of ordinary earth roads, economical maintenance depends largely upon proper original construction. The use of too fine sand and the insufficient mixing of the sand and clay are the common defects of construction that should be remedied by proper maintenance.

The surface should be kept smooth and properly crowned by the use of the road drag, particularly after severe or long-continued wet spells. If a hole forms because of an excess of clay, it should be filled mainly or entirely with coarse sand, after first loosening the material in the bottom of the hole with a pick so that the new material will bond with the old. Sometimes the fine sand washes to the side of the road and leaves an excess of clay, in which case a thin layer of new coarse sand should be spread upon the surface when it is soft or at least wet. The sand that has washed out should never be used again.

If the whole surface has a tendency to rut and form holes in wet weather, it usually means that too much clay has been used in the construction of the road; and it may then be necessary to cover the entire surface with a layer of sand and harrow it in. If, on the other hand, the surface is too sandy, clay must be added in the same way.

If lack of proper dragging has allowed the road to become badly worn, then it must be plowed up with a rooter plow, after which it should be harrowed, preferably with a disk harrow, and be re-shaped with a grader.

266. The ability of a sand-clay road to carry travel, particularly motor-driven vehicles, is indicated roughly by Table 23, page 149.

267. Apparently, in the Southern States, representative sand-clay roads are maintained in reasonably good condition at an expense of $5 to $10 per year per mile, the chief or sole expense being for dragging.

TABLE 23

APPROXIMATE TRAVEL ON SAND-CLAY ROADS IN GEORGIA †

Type of Vehicle.	Average Numbers of Vehicles both Ways, per Day.											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Horse-drawn:												
Buggies	20	30	35	25	20	20	20	25	40	40	25	20
1-horse wagon (net load 750 lb.)	60	90	100	75	60	60	60	70	120	120	75	40
2-horse wagon (net load 1,500 lb.)	60	90	120	75	60	60	60	70	120	120	75	40
4-horse wagon (net load 3,000 lb.)	4	6	6	4	4	4	4	5	8	8	4	4
Total	144	216	261	179	144	144	144	170	288	288	179	104
Motor-driven:												
2-passenger automobile	10	10	15	20	20	30	30	20	30	30	20	10
4-passenger automobile	6	6	8	10	10	15	15	10	15	15	10	6
6-passenger automobile	2	2	4	6	6	8	8	8	8	8	6	2
Trucks (net load 1,500 lb.)	2	2	3	4	4	2	2	2	4	4	2	2
Total	20	20	30	40	40	55	55	40	57	57	38	20
Per cent motor-driven	12	8	10	18	22	28	28	19	14	14	26	16

† Trans. Amer. Soc. of Civil Eng'rs, Vol. 77 (1914), p. 1492.

CHAPTER V

GRAVEL ROADS

270. Gravel may be defined as a mass of small, more or less rounded fragments of stone which have been broken out and shaped by the action of water or ice. When properly used gravel makes an excellent road surface; and is much used on account of its wide distribution, the ease with which it can be applied, the good results obtainable under widely varying conditions of soil, climate and travel, and the low cost of construction and maintenance under a moderate amount of travel. Many gravel roads have been poorly constructed or inadequately maintained, or over-burdened with travel; and as a consequence many people believe the building of gravel roads a waste of money under any condition. Nevertheless good gravel roads have a large field of usefulness. Gravel roads constitute about one third of the total mileage of improved roads in the United States; and in 1914 constituted 41 per cent of the state-aid roads.

A gravel surface is most suitable for country highways not having exceedingly heavy traffic, for unfrequented streets in villages and small cities, and for park roads.

Art. 1. The Gravel

271. Requisites for Road Gravel. To be suitable for road-building purposes, gravel should fulfill the following conditions: 1. The fragments should be so hard and tough that they will not be easily ground into dust by the impact of wheels and hoofs. 2. The pebbles should be of different sizes, each in the proper proportion. 3. There should be intermixed with the coarser particles some material which will cement and bind the whole into a solid mass.

272. Durability. From the nature of its origin, it is apparent that gravel may differ widely in the nature of the stones composing it. Not only do different gravels differ from each other, but any

particular gravel may be composed of fragments of a variety of rocks. Having been transported a considerable distance by water and ice, gravel is usually fairly durable, since the softer and more friable fragments have been worn away. In many parts of the country the rocky fragments transported by water and ice are more durable than any of the native rocks.*

273. Sizes. If the pebbles are too large, the road will not be homogeneous, and the large stones will work to the surface under the action of traffic and frost; but, on the other hand, if the pebbles are too small, the gravel will partake too much of the character of sand, and will be difficult to bind properly. The best results are obtained when the largest pebbles are not more than $\frac{3}{4}$ to 1 inch, or at most $1\frac{1}{2}$ inches, in greatest dimension. With stones larger than 1 inch, it is difficult to keep the surface from breaking up when dry. Small gravel makes a pleasanter road to ride upon and one that is easier to keep in order. If stones larger than $1\frac{1}{2}$ or 2 inches are present in the gravel, they may be screened out and used in the foundation (§ 303).

It is desirable that the several sizes should be so proportioned that the smaller ones are just sufficient to fill the interstices between the larger ones, since then less binder is required. The binder is usually the least durable ingredient, and hence the less there is of it the better. Gravel can often be improved by screening—either to remove an undesirable size or to separate it into several sizes afterward to be combined in new proportions. The proper proportion depends upon the nature of the gravel—whether the binding material is already present in the form of dust, or whether some of the pebbles must be crushed to produce the binder.

274. Binder. The most important requisite for good road-building gravel is that it shall bind or pack well. If it does not pack well, the wheels will sink into the gravel and increase the tractive resistance, and the rain water will penetrate the road-bed and soften it. To bind well, the several fragments should be in contact with one another at as many points as possible, in order that they may be firmly supported, and that friction may act to the best advantage to resist displacement. To secure contact at every point, all the interstices between the fragments should be filled—those between the large pebbles, with small pebbles; those between the small pebbles, with sand grains; and, finally, those between the sand

* For a discussion of the merits of the principal stones for road-building purposes, see Art. 1, Chapter VI.

grains, with some finer material, called a binder. The binding material must be very finely divided, so that it can be worked into the smallest interstices; and for this reason, it is the least durable part of the gravel, being easily washed out or blown away. For the best results, then, the sizes of the coarser particles should be so adjusted as to require a minimum amount of binder.

The binding material may consist of clay, loam, silica, stone dust, iron oxide, etc., or some other ingredient which will crush under traffic and furnish a fine dust.

Clay is by far the most common binding material; but the only recommendations for it are (1) that it is easily reduced to an impalpable powder by the action of wheels or by water, and (2) that it is often found already mixed with the gravel, and (3) that if it must be artificially mixed, it is plentiful and cheap. Clay is an undesirable binder, since its binding action depends in a large measure upon the state of the weather. During a rainy period it absorbs water and loses its binding power, and the road becomes soft and muddy; while in dry weather it contracts and cracks, thus releasing the pebbles and giving a loose surface. Clay is also very susceptible to the action of frost; and consequently when the frost is going out, a gravel road with a clay binder ruts up badly and frequently breaks entirely through. When the weather is neither too damp nor too dry, a gravel road with clay binder is very satisfactory. The clay should be no more than enough to fill the voids in the pebbles and sand, and for a good road-gravel should not exceed 15 to 20 per cent of the mass. Not infrequently much greater quantities of clay are present. This surplus may sometimes be removed by screening; but often it can be removed only by washing—a process which is usually so expensive as to be prohibitive.

Loam is chiefly clay mixed with sand and a little vegetable matter, lime, etc.; and as a binding material has all the characteristics of clay.

A very finely divided silica, easily mistaken for clay, is occasionally present in gravel, and makes an excellent binding material.

Iron oxide is frequently found as a coating on the pebbles in such quantities as to cement them firmly together. These ferruginous gravels when broken up and put upon a road, will again unite—often more firmly than originally, because of the greater pressure—and form a smooth hard surface, impervious to water. They are much used in road building, gravel from Shark River, N. J.,—much used around New York City—and that from the Ohio

river near Paducah, Ky.,—largely used in the neighboring states—being examples.

275. Comparatively coarse gravel frequently contains some other ingredients, as, for example, fragments of limestone or shale, which under the action of traffic and the weather reduce to a powder and form a good binding material. Sometimes gravel contains bits of iron-stone (clay cemented with iron oxide) in the form of thin flat chips which break and crush easily under the wheels, and if present in any quantity make a most excellent binding material.

276. The binding action referred to in the preceding discussion is mechanical; and we come now to the consideration of an action not yet well understood, but which for the present at least will be called chemical action. Experiments seem to prove that if fine powder of certain stones is wetted with water and subjected to compression, a true chemical cementation takes place. Consequently some stones when broken into small fragments, wetted and traversed by heavy wheels or by a road-roller will be cemented together to a considerable degree. This cementation is due to the fact that the friction of one small piece of stone upon another produces a very fine powder at the point of contact, which when wetted and compressed, forms a weak cement. Owing to the rounded surfaces of water-worn pebbles, this cementing action is much less with gravel than with rough angular fragments of broken stone; but with gravel composed of undecayed rocky fragments this action takes place to a considerable degree. As a rule, pebbles of bluish color will thus cement together, while reddish or brown ones will not, which accounts in part at least for the well known superiority of blue gravel for road purposes. Trap rock possesses the property of cementation in a high degree, and hence trap gravel is a very excellent road-building material. Limestone possesses a fair degree of cementation, but is too soft to wear well. Quartz wears well but produces little or no dust for cementation, and besides its surfaces are so smooth and hard that the binder has but little effect; and therefore it rarely happens that a gravel of which more than one half of its bulk is white quartz pebbles proves to be a good road gravel.

The cementation of rocky fragments is much more important in a water-bound macadam road than in a gravel one, and therefore the subject will be more fully considered in Chapter VI.

277. The binding elements heretofore discussed exist naturally in the gravel; but gravels are often found that do not contain any

binding material, and in such cases it is necessary to add some cementing material.

Clay, shale, hard-pan, marl, loam, etc., are often used for this purpose, chiefly because they are so plentiful and easily applied; but none of them are suitable for the purpose, as they all have the characteristics of a clay binder (see § 274). With any of them, it is difficult to keep the gravel from breaking up—particularly under heavy traffic.

In some localities a poor iron ore is found, which, when mixed with gravel, makes an excellent binder and gives a smooth hard road surface. Bog iron-ore, which occurs in marshes, is usually very good for this purpose.

The fine dust from a stone crusher, when mixed with gravel, will bind it together; but it is seldom feasible to use stone dust on account of the expense. When this method of binding gravel is resorted to, the construction partakes of the character of a water-bound macadam road—a subject foreign to this chapter (see Chapter VI). The chief difference between a gravel and a crushed-stone road is in the thoroughness of the binding. The binding of a gravel road is due chiefly, and usually solely, to the mechanical action of the binder; while the binding of the broken stone is due to both the mechanical and the chemical action of the binder, and both are stronger with rough angular fragments of broken stone than with water-worn pebbles.

278. Distribution of Gravel. The gravel beds of the glacial drift furnish excellent road-making materials. The glacial ice sheet, often a mile or more thick, covered New England and Canada and all of the United States north of an irregular line starting on the Atlantic Coast a little south of New York City and running thence successively to the southwest corner of the State of New York, to Cincinnati, to a point a little north of the mouth of the Ohio river, to the mouth of the Missouri river, to Topeka, Kansas, thence north and west a little west and south of the Missouri river to the head waters of that stream, and thence west to the Pacific ocean. All of the area north of the above described line was covered with the ice sheet except small portions of southeastern Minnesota, northeastern Iowa, northwestern Illinois, and a considerable portion of southwestern Wisconsin. As this ice sheet crept to the southward, it rent great quantities of stone from the bed rocks; and these materials were borne southward, either in the slow-moving ice or hurried along by the violent currents of water which swept

forward to the margin of the ice field. Thus impelled the under-ice streams were able to bear toward the margin of the glacier great quantities of stone. The original range of the glacial gravels has been greatly extended here and there by the streams, which, flowing southward beyond the drift belt, have often carried quantities of the hard detritus for many miles beyond the limits of the ice-field.

Unfortunately the glacial gravel deposits have not been studied from the point of view of the road-maker. However, it is known that east of the Hudson river the glacial supply of road gravels is only here and there of economic importance, for in most of that field the glacial waste lies on native rocks which are suitable for road-making; and that from the Hudson to the Mississippi, the glacial deposits of bowlders and gravel afford better road-building materials than any of the native rocks. Glacial gravels exist in considerable quantities in western Pennsylvania, in the greater part of Ohio, in northern Indiana, and in northern Illinois, and to some extent in several of the states of the Northwest.

279. South of the glacial district, the rocks exposed to the weather have decayed by a process of leaching, which in many cases has removed strata hundreds of feet thick. The rocky portion is removed in proportion to its solubility; and, as a result, there are often left concretions of cherty matter which were originally contained in beds of limestone. This cherty residuum of flinty material generally lies in a comparatively thin sheet of fragments mingled with sand and clay; but occasionally it is found in deposits from which the clay and sand have been removed by recent or ancient streams, leaving the material well suited for spreading upon a road. Sometimes this cherty residuum is found in layers of fragments many feet thick, and is valuable for road-building in a locality where more suitable material is scarce. The presence of chert is often revealed by the gullies in the plowed fields and along the streams. In some localities very good roadways are constructed simply by shoveling these fragments from the stream beds and depositing them on the road.*

This cherty deposit is a valuable road material in the southern portion of the Appalachian mountains, and along the Ozark foothills in southern Illinois (particularly in Alexander and Union counties), in southern Missouri, and in northern Arkansas. Chert is found in some of the states of the Northwest where the glacial

* For a discussion of chert as a road-building material, see § 295.

erosion was small, so that the rocks that had decayed before the glacial time were not entirely removed. In southwestern Arkansas the gravels consist of fragments of novaculite or razor stone—a material of nearly the same geological origin and physical characteristics as chert. In many places in that state the novaculite gravels form extensive beds, 20 or more feet thick. At the southern extremity of the Appalachian mountain system is a wide-spread deposit of gravel, termed the La Fayette formation, whose geological origin is not determined. This deposit often attains a thickness of 40 to 50 feet, and is a valuable source of road-building material.

280. If gravel be defined as material prepared by nature ready to be laid upon the road, then a few words are in place here concerning iron ore. In some localities there are low-grade iron ores which, owing to the admixture of various impurities, are unfit for use in making iron, but may be valuable for road building. These low-grade ores are widely distributed; and generally wherever limestone occurs below a considerable thickness of sandstone, the upper portion of the limy layer will be found to contain iron, and will probably be a fair road material. A lean iron ore is frequently found in marshes; and this variety, known as bog ore, usually makes excellent roads, since it crushes readily and gives a smooth hard surface.

281. Exploring for Gravel. In searching for gravel in the glaciated district, the following suggestions by Professor Shaler * will be useful:

"In the process of retreat of the ice, the deposits which it left were accumulated under several quite diverse conditions. One of these produced the till, or commingled coarse and fine materials, which had been churned up into the ice during the time of its motion, and came down, when the melting occurred, as a broad, irregularly disposed sheet which, with rare exceptions, is to be found in all parts of the glaciated district, save where it has been swept away by streams.

"Again, from time to time during the closing stages of the ice age, the prevailing steadfast retreat of the ice was interrupted by pauses or re-advances. In these stages there was formed along the margin of the ice-field what is called a frontal moraine, composed of debris shoved forward by the glacier or melted out of it along its front. These moraines are in most cases traceable, where they have not been washed away or buried beneath later accumulations,

* American Highways, N. S. Shaler, Professor of Geology, Harvard University, p. 71–73.

in the form of a ridge-like heap of waste, which, as we readily note, contains much less clay and sand and therefore a larger proportion of gravel and bowlders, than the sheet-like deposit of till above described. In some cases these moraines are very distinct features in the landscape, appearing, from the number of large bowlders which they expose, much like ruined walls of cyclopean masonry. More commonly they are found in the form of slight ridges, which may be covered with fine material, but commonly exhibit here and there projecting bowlders. In general it may be said that the moraines afford much better sites for pits from which road materials are to be obtained than the till, and this because of the prevailing absence of clay and sand in the deposits.

"Here and there in almost all glaciated districts, especially in the valleys of the greater streams, there may be found narrow ridges, often of considerable height, and almost always extending in the direction of the ice movement. These ridges are generally termed by geologists eskars, and often have a tolerable continuity for scores of miles at right angles to the ice front. A section of them shows generally a gravelly mass, nearly always free from clay and often containing little sand, though occasionally there is an abundance of large bowlders, which have a prevailing rounded or water-worn form. These eskars were doubtless formed in the caves beneath the ice through which the ancient sub-glacial streams found their way. These under-ice rivers were much given to changing their position, and as a stream lost its impetus it was apt to fill its ancient arched-way with debris, which in its time of freest flow would have been sent forward to the ice front. At many places in New England and in New York these eskars contain large and useful deposits of gravel, and also occasionally quantities of bowlders well fitted for crushing as regards their size and hardness. In the Western States, because of the general coating of deep soil, these eskars are less easily found; but they exist there, and should be sought for.

"Where the eskars terminate, as they commonly do, on a morainal line, there is almost invariably found, immediately in front of their southern terminations, a delta-like deposit which, though generally composed in large measure of sand, frequently contains near the moraine extensive accumulations of useful gravel and small bowlders which are fit for crushing.

"Information may be had from the banks of streams, where by chance they have cut below the deep coating of fine materials. The

existence of any distinct up-rise of the surface affords some reason to expect that the coarse glacial waste may be at that point not very deeply hidden."

282. When a gravel road is to be built, if the local gravel resources have not already been thoroughly explored, every reasonable effort should be made to ascertain the extent and character of the available deposits of gravel. To test a gravel deposit, test holes or wells should be sunk at regular intervals over the deposit. These holes should be large enough for a man to get down into them and to examine the gravel in place and to collect samples. Care should be taken that the samples are truly representative. Note should be made of the amount and character of the overlying material, of the depth of the gravel deposit, and of the dip of the strata.

283. CHARACTERISTICS OF DIFFERENT GRAVELS. Any gravel which stands vertical in the bank, showing no signs of slipping when thawing out in the spring, requiring the use of the pick to dislodge it, and falling in large chunks or solid masses, is sufficiently clean and free from clay for use on the road, and usually contains just enough cementing material to cause it to pack well.

Pit gravel usually contains too much earthy material, and can be greatly improved by screening. Gravel is still being deposited in drifts and bars by streams, and this will be found to partake of the character of the pit gravel of the locality, except that it generally contains less clay, and may have an excess of sand. This is often called river gravel, and is one of the best sources of road material. Lake gravel varies greatly in character. It is usually free from earth and contains sufficient sharp sand to pack well; but is liable to be slaty—an undesirable quality.

284. Composition of Representative Gravels. In an endeavor to determine the composition necessary for a road-building gravel, samples were obtained of a number of gravels that had given satisfactory service in the road. The samples in each case were selected by a person thoroughly conversant with the use of that particular material, and are believed to be fairly representative.

Table 24, page 160, shows the sieve analysis of these gravels. Each sample was first washed in successive waters until the water remained clear, and then the wash water was allowed to stand until the matter in suspension was precipitated. The precipitate was dried in an oven to a constant weight and then weighed; and the washed gravel was air-dried, and then sifted and weighed. The per cent of voids in the washed gravel was obtained by gently ram-

ming the gravel under a measured quantity of water in a small metal cylinder, the ramming not being severe enough to crush any of the pebbles or fragments.

Table 25, page 161, shows the results of a mineralogical analysis of such of these gravels as had passed a screen having $\frac{1}{4}$-inch meshes. The matter recorded in Table 24 as being in suspension is called clay in Table 25, although part of it was doubtless organic matter and part fine sand, but the error is not material.

285. To study these gravels further, each will be considered in order.

1. *Urbana.* This is a screened drift gravel obtained near Urbana, Champaign Co., Ill., which has been used in a few instances on private driveways. Table 25 shows only 3.8 per cent of clay present, which will have only a small binding effect. There is 7.6 per cent of iron oxide (Fe_2O_3) in the clay, but there is so small a proportion of clay in the gravel that the iron contained in it will have an inappreciable binding effect. The principal source of binder is, then, the 65 per cent of ferruginous limestone. Limestone itself when pulverized makes an excellent binding material. However, in this case only a small part of the limestone is in the form of flat chips that may be easily crushed under the wheels, but the most of the fragments are rounded and not easily crushed except by comparatively heavily loaded wheels. There is only a small per cent of crystalline rocks present, and these are hard and not readily crushed, and consequently can not materially affect the binding qualities of the mass. The gravel also contains 22.2 per cent of quartz; but this material is very hard and not easily crushed, and besides its dust is almost wholly devoid of cementing properties. Both the quartz and the crystalline rocks are quite sharp and angular, which is a very desirable condition, and aids the binding action of the clay and the limestone dust. This gravel packs slowly in the road, particularly under the light traffic of a private driveway; but under moderate traffic makes a fairly good road, and is not much affected by freezing and thawing.

2. *Decatur.* This is a gravel much used on the country roads near Decatur, Macon County, Ill., with satisfactory results. This gravel has a comparatively large amount of fine sand. An examination of Table 25 shows that it contains more than twice as much clay as the Urbana gravel, but only about one third enough to fill the voids. A considerable portion of the limestone both of the pure and the ferruginous—a total of 30 per cent,—is in thin

TABLE 24

SIEVE ANALYSIS OF ROAD-BUILDING GRAVELS

Ref. No.	Size of Mesh.	1. Urbana.	2. Decatur.	3. Lexington.	4. Rockford.	5. Peekskill.	6. Buck Hill.	7. Rock Hill.	8. Shark River.	9. Oaktown.	10. Shaker Prairie.	11. Paducah.	12. Rosetta.
1	Per cent caught on 2-inch mesh.....	0.0	0.0	0.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	" " 1 "	0.3	1.1	4.6	35.6	2.1	0.0	0.0	0.0	1.5	9.1	20.5	1.9
3	" " $\frac{1}{2}$ "	9.6	12.2	10.0	23.5	41.3	11.7	3.3	0.8	12.2	12.6	20.5	17.8
4	" " $\frac{1}{4}$ "	13.0	10.5	8.7	7.4	25.5	11.0	13.4	12.7	18.6	9.1	8.8	11.0
5	" " $\frac{1}{16}$ "	41.1	14.8	20.2	9.1	17.8	8.4	25.1	33.2	47.5	21.3	13.8	22.3
6	" " $\frac{1}{27}$ "	12.1	3.9	15.3	3.2	2.2	20.4	14.0	7.4	8.9	9.3	5.2	20.0
7	" " $\frac{1}{40}$ "	3.9	7.8	15.9	2.7	1.8	8.2	7.2	5.5	3.5	9.3	1.9	10.5
8	" passing $\frac{1}{40}$ "	16.2	40.0	21.0	8.7	8.4	20.2	16.3	20.0	6.1	18.8	21.8	10.4
9	" in suspension.....	3.8	9.6	4.2	3.2	0.9	20.0	20.7	20.2	1.8	9.8	7.8	5.9
	Total.....	100.0	100.0	99.9	99.4	100.0	99.9	100.0	99.6	100.1	99.3	99.7	99.8
	Per cent voids in washed gravel....	25.5	30.5	27.3	29.6	30.5	26.3	34.0	28.2	25.6	24.2	24.5	25.3

TABLE 25

MINERALOGICAL ANALYSIS OF ROAD-BUILDING GRAVELS

Ref. No.	Mineral Constituents.	1. Urbana.	2. Decatur.	3. Lexington.	4. Rockford.	5. Peekskill.	6. Buck Hill.	7. Rock Hill.	8. Shark River.	9. Oaktown.	10. Shaker Prairie.	11. Paducah.	12. Rosetta.
1	Limestone,—pure carbonate of lime	.....	21.9	.....	.....	.....	.....	.....	.....	18.9	28.6	.....	.....
2	ferruginous	65.0	8.1	21.0	.....	33.5	.....	.....	.....	.....	.....	.....	.....
3	with iron and silica	.....	.....	.....	73.8	.....	.....	.....	.....	2.0	2.4	.....	.....
4	siliceous	.....	.....	58.0	.....	.....	.....	.....	.....	.....	.....	.....	.....
5	Sandstone,—ferruginous	.....	7.1	.....	.....	8.7	.....	.....	.....	0.4	.....	.....	.....
6	finely divided	.....	.....	.....	.....	.....	.....	10.5	.....	0.5	3.7	.....	.....
7	coarse	.....	.....	.....	.....	.....	.....	3.8	.....	.....	.....	.....	.....
8	Metamorphic rock,—iron, silica, mica	.....	.....	.....	.....	4.9	.....	.....	.....	2.0	.....	.....	.....
9	iron, silica, limestone	.....	.....	.....	.....	.....	6.0	.....	.....	4.6	2.7	.....	.....
10	Conglomerate,—iron	.....	.....	.....	1.7	.....	.....	.....	.....	.....	.....	.....	.....
11	limestone and quartz	.....	.....	.....	12.3	.....	.....	.....	.....	.....	.....	.....	.....
12	Crystalline rocks,—acidic	4.6	10.1	1.4	.....	15.5	.....	.....	.....	12.1	11.4	.....	.....
13	basic	4.3	19.7	1.1	4.3	14.2	.....	.....	.....	13.2	13.2	.....	.....
14	Quartz, crystalline	22.2	23.3	13.7	4.6	22.1	73.9	64.3	78.8	38.8	27.8	.....	94.0
15	Chert, ferruginous	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	92.9	.....
16	Shale	.....	.....	.....	.....	.....	.....	.....	.....	5.3	0.7	.....	.....
17	Clay	3.8	9.6	4.2	3.2	0.9	20.0	20.7	20.2	1.8	9.8	6.8	5.8
	Total	99.9	99.8	99.4	99.9	99.8	99.9	99.3	99.0	99.6	100.3	99.7	99.8
	Per cent of iron in the clay	7.6	9.1	9.1	9.4	.....	16.5	18.1	9.9	4.6	6.4	8.1	22.1

friable chips, and is easily crushed by the traffic, thus making an excellent binder. The ferruginous limestone contains an unimportant proportion of iron; but the ferruginous sandstone is heavily charged with iron oxide, which makes a good cementing material. This gravel makes a smooth, hard surface, reasonably free from dust in the summer and mud in the winter.

3. *Lexington.* This gravel is used with entire satisfaction in and around Lexington, McLean County, Ill., for country highways. Notice that the clay is equal to only one seventh of the voids. Nearly all of the 21 per cent of ferruginous limestone consists of thin chips which are easily crushed by the traffic. Some binder is probably obtained from the 58 per cent of siliceous limestone. The per cent of crystalline rocks present is very small, and can not materially affect the quantity of the gravel. The amount of quartz is less than in the preceding gravels, and is an unimportant element.

4. *Rockford.* This gravel has given satisfactory service in Rockford, Winnebago County, Ill., probably under more exacting conditions than any of the preceding. This is considerably the coarsest gravel in Table 24. Notice that this gravel contains, roughly speaking, only about one tenth enough clay to fill the voids. The chief source of binder is the limestone which exists in the form of pebbles, but contains no considerable amount of iron or silica. The basic crystalline rocks by decomposing may furnish a little binder; but as they are round hard pebbles, not easily crushed, the binder derived from this source can be of no practical importance. Very little cementing material may be derived from the iron conglomerate or from the limestone and quartz conglomerate.

5. *Peekskill.* This gravel is from Roa Hook, a "point" in the Hudson river near Peekskill, N. Y., and is much used in and around New York City, where it is considered one of the best road gravels. Notice that the clay is less than one thirtieth of the volume of the voids. Considerable binding material is doubtless derived from the ferruginous limestone, which contains a comparatively small per cent of iron. The iron in the ferruginous sandstone is too small in amount to be appreciable. Some binder is doubtless derived from the metamorphosed rocks containing iron, silica, and mica. Notice that there are nearly 30 per cent of crystalline rocks, which upon being finely pulverized will furnish an excellent cementing material, particularly after being decomposed. This gravel requires considerable rolling with a heavy roller to crush the several ingredients and liberal

sprinkling to work the pulverized material into the voids, before the mass binds. All other gravels in Table 24 bind and make fair roads under ordinary traffic.

6. *Buck Hill.* This gravel was obtained from the Buck Hill pit at Tuckahoe, N. J. It was recommended as a representative gravel by Hon. Henry I. Budd, State Commissioner of Public Roads of New Jersey. This gravel consists chiefly of clay and partially rounded quartz pebbles. The metamorphosed rock is angular and friable. The clay is probably enough to fill the voids when the gravel has been compacted by traffic. This is the first of the samples in which the iron contained in the clay is appreciable, and the iron doubtless has an important part in binding the road. This gravel is used for road building without rolling.

7. *Rock Hill.* This sample was obtained from the Rock Hill pit at Tuckahoe, N. J., and is substantially the same as No. 6, except in having a greater per cent of voids and in containing some sandstone which crushes easily and materially reduces the voids of the gravel after it has been compacted in the road. It is said that the best results are obtained by mixing this and the preceding gravel half and half.

8. *Shark River.* This gravel was obtained from the Manasquan Gravel Co. of Asbury Park, N. J., and is much used in southern New Jersey and around New York City. It consists wholly of clay and small rounded pebbles of pure white quartz, and consequently the only binding material is the clay and the 2 per cent of iron contained in it.

9. *Oaktown.* This is a gravel obtained from the Wabash river by dredging, a few miles above Vincennes, Ind., which has been used on the roads entering Oaktown, Knox Co., Ind. There is very little clay in this gravel,—only 7.1 per cent, if the shale be considered as clay, as it is practically. The chief source of binding material is the 18.9 per cent of carbonate of lime, much of which is in the form of flat chips. The metamorphic rocks are also in thin chips, and are easily pulverized. The crystalline rocks and the quartz are comparatively rough and angular. In service the limestone pebbles grind up under traffic, and the road becomes hard and firm, and is not much affected by freezing and thawing.

10. *Shaker Prairie.* This gravel is found in a pit on Shaker Prairie, west of Oaktown, Knox Co., Ind., and consolidates under traffic much more quickly than the preceding. This gravel contains a comparatively small amount of fine sand, being in this respect

about on a par with the Peekskill gravel—see No. 5, Table 24. It contains a comparatively large amount of clay, being in this respect similar to the New Jersey gravels—No. 7, 8, and 9 in Tables 24 and 25. This gravel has more iron in the clay than any of the samples except the Tuckahoe gravels—No. 6 and 7. The limestone is in comparatively large rounded pebbles, and not easily crushed under traffic. The road is bound almost wholly by the clay and the iron in it, and by the pulverized limestone.

11. *Paducah.* This gravel came from a pit about 2 miles west of Paducah, Ky., on the Ohio river at the mouth of the Tennessee river. It makes excellent roads that pack quickly under traffic and are not much affected by freezing and thawing. The coarse material consists of water-worn chert pebbles, and is cemented by ferruginous clay. The chert is brittle and crushes with a sharp splintery fracture, and consolidates readily under traffic, the sharp angular fragments giving an immobile mass and offering excellent surfaces for the cementing action of the binder.

12. *Rosetta.* This gravel comes from the Rosetta pit at Fort Gibson, near Vicksburg, Miss., and is much used by the Illinois Central Railroad as ballast. It is here included under the belief that it will also make good wagon roads. The quartz pebbles are quite rough and angular, and in the pit seem to be quite firmly cemented together by ferruginous clay.

286. *Conclusion.* From the preceding, the following conclusions may be drawn. 1. The relation between the proportion of voids and the per cent of clay is no indication of the road-building qualities of a gravel, for under traffic some of the fragments may crush and decrease the per cent of voids and at the same time increase the amount of the binding material. 2. The friability of the pebbles has a greater effect upon the road-building qualities of a gravel than the per cent of the voids. 3. The binding material may be clay, or clay and iron, or pulverized limestone, or all of these combined. The less clay the more slowly will the road bind, but the less it will be affected by frost.

A study similar to the preceding will not certainly determine the suitability of a gravel for road purposes, but it will throw valuable light upon its probable behavior in the road. The only sure way to determine the road-building qualities of a gravel is to test it by actual service, for much depends upon the friability of the pebbles, the weight of the traffic, the climatic conditions, etc. In applying the test of actual service, particularly to determine the

relative merits of two gravels, account should be taken of (1) the nature of the soil, (2) the care employed in preparing the foundation, (3) the quantity of material used, (4) the amount and character of the traffic, (5) the care given to maintaining the road, and (6) the length of time the material has been in service. The character of a gravel road is generally indicated by the sound of the metal tires of the wheels of the vehicles passing over it. If the wheel makes a continuous crisp gritty sound, the road is reasonably good; if the gritty sound is absent, there is probably too much earthy matter on the surface; and if the sound is intermittent, there are probably too many large pebbles in the surface.

ART. 2. CONSTRUCTION

288. The subgrade for a gravel road should be prepared in substantially the same manner as for an earth road (see Art. 1, Chapter III). Indeed a first-class earth road is the best foundation for a gravel road.

289. DRAINAGE. In no case should the drainage be neglected —neither the side ditches nor the underdrainage. With the hard, impervious surface of a gravel road, the water reaching the side ditches is greater than with an earth surface; and therefore the side ditches should be larger for gravel and broken-stone roads than for earth ones.

A gravel road upon an undrained soil entails a needless expense for maintenance, and is never so good as if the road-bed had been thoroughly underdrained. Not infrequently a thin coating of gravel has been thrown upon an undrained foundation, only to sink out of sight in a year or two, and the attempt to secure a gravel road has been abandoned. In such cases a comparatively small expense for underdrainage would probably have resulted in a fair road instead of a failure. The total amount of good road-building material in the world is small in comparison with the possible future demand, and therefore it is a public misfortune to have any of it wasted in bungling attempts at road building. One purpose of gravel is to give a more or less rigid layer which will distribute the concentrated pressure of the wheels over a sufficiently large area of the earth foundation to enable it to support the load without indentation. The thickness of gravel required to support the load depends upon the degree of the drainage, since the more water in the earth the less load it can support. Underdrainage costs

nothing for maintenance, and decreases the amount of gravel required, as well as the cost of maintaining the surface.

290. The tile should be placed under the side ditches—as described for earth roads (§ 116). Some writers recommend that a tile be laid under the middle of the gravel with the earth surface sloping both ways to the tile. There are several objections to this construction: (1) sloping the earth surface is not of much advantage, and (2) it needlessly increases the depth of the gravel; and (3) if the road is otherwise well made, the surface should be practically impervious to water. See § 124.

Some writers advocate a tile each side of the graveled portion, with short lines of tile running each way from the center of the roadway obliquely to the side tile, these "miter drains" to be placed 15 feet apart in wet places. Clearly this construction is based upon a misapprehension of the source of the water reaching a drain tile. The water that enters a tile comes from below and not directly down from above. It is abundantly proven that in an earth road needing underdrainage, little or no water penetrates the surface; and with good gravel roads there will be still less. Therefore "miter underdrains" below the graveled portion of the roadway are absolutely worthless, and tiles at the edges of the hardened way are no better than tiles under the side ditches.

291. WIDTH. For a discussion of the principles governing the width of improved way and also whether it shall be located in the center or at one side of the wheelway, see § 95–98. For a consideration of the excess width on curves, see § 97.

292. MAXIMUM GRADE. For a general discussion of maximum grades, see § 79–86. A committee of the American Society of Civil Engineers recommends that the maximum grade permissible be 12 per cent—see Table 15, page 57. In the matter of permissible maximum grades, gravel and macadam roads are in the same class. For data concerning existing maximum grades on water-bound macadam roads, see § 112.

293. CROWN. The same general principles concerning the crown apply in gravel roads as in earth roads—see § 130–31. The slope of the gravel surface from the center to the side should be at least one quarter of an inch per foot, and it should not be more than three quarters of an inch per foot. The first is about right for park drives, which have light traffic and are well cared for. If the drive is narrow, the crown may be a little greater than this; but if it is broad, the crown should be less, to prevent the surface

from being gullied out near the gutters by the water running from the center to the sides. The maximum crown, as above, would be about right for a country gravel road with heavy traffic, or for a street. If the gravel contains an excess of clay, the crown should be greater than the above maximum, as the surface will be liable to rut up.

Frequently gravel roads have an excessive crown, which forces travel to use a narrow strip in the center—see § 129. This results from the fact that the gravel is placed thicker at the center than at the edges; and thus the surface of the gravel is given a greater crown than the original earth road, while a gravel road should have a less crown than an earth one.

A committee of the American Society of Civil Engineers recommends a maximum crown of 1 inch per foot of half width and a minimum of half that amount—see Table 16, page 65.

294. For a rule for super-elevation on curves, see § 90.

295. FORMS OF CONSTRUCTION. There are two forms of construction of country gravel roads, which differ as to the manner of preparing the subgrade to receive the gravel. In one form the gravel is simply deposited on the surface in a strip along the middle of the former earth road; and in the other a trench is excavated in which the gravel is placed. For convenience of reference the former will be called Surface Construction, and the latter Trench Construction.

296. Surface Construction. The crudest form of this method of construction consists in dumping gravel, as it comes from the bank, in piles in line on an earth road. The quantity of gravel is gaged by dumping a load in one, or two, or three lengths of the wagon. Little or no attention is given to leveling off the top of the piles, and it is not rolled except as travel is forced upon the ridge when the earth upon the sides gets muddy. For the first year or two after construction, such a gravel road is little if any better than an earth one. The surface is full of cradle holes and is easily cut into ruts; and the loose material absorbs the rain, and becomes mixed with the soil below. If the gravel is good, the road becomes fairly good after the gravel has been packed by travel and after the holes have been filled up by the addition of new material. This form of construction is common where gravel is plentiful, the work usually being done by labor road-tax.

297. Another form of surface construction consists in setting up two lines of plank on edge and filling the space between them

with gravel. The gage planks are set on edge, 8, 10, or 12 feet apart according to the importance of the road, and the gravel is filled in between the planks, 8 or 10 inches deep at the sides and 12 or 15 at the center. Of course, when the boards are moved forward to be used again, the edge of the gravel spreads out and takes the natural slope, and under traffic it spreads out still further. Ordinarily in this form of construction the gravel is not rolled, and there is little or no driving over it by teams engaged in the construction. The only advantage of this method over the preceding one is that it affords a means of gaging the depth of gravel and of determining the quantity used; and the chief objection to it is that when gravel is put on in a thick layer, the lower part is not consolidated well, at least not for a considerable time, and therefore the surface is liable to break up. This form of construction is very common.

298. In the best form of surface construction, the former earth road is first smoothed up with the scraping grader and if necessary the crown is reduced. If after smoothing the surface with the grader, the foundation is not already firm and solid, it should be rolled. Next a layer of gravel 4, or at most 6, inches deep is spread upon the prepared subgrade, and leveled—either by hand with a shovel and rake, or with a harrow or scraping grader. In dumping from a wagon or cart, the larger stones will roll to the outer edge of the heap; and hence in leveling the gravel care should be taken that these are scattered and covered deeply with fine material, for otherwise the road will not have an uniform texture and will wear unevenly and the large stones are liable to work to the top.

If the teams hauling the gravel are required to drive over that already placed, the road will be consolidated much sooner, but as the tractive resistance on loose gravel is very great, there is some disadvantage in this requirement. If it is to be insisted upon, the construction of the road should begin at the end nearest the gravel pit. The gravel can be consolidated with a roller, but not as effectively as by traffic, since no roller gives so great a pressure as the wheels of loaded wagons (see § 378). But heavy loads should not be permitted to go over the road while the surface is wet and soft, for fear the wheels will cut through and mix the earth and the gravel. While the gravel is being consolidated by the passage of the teams employed in the construction or by ordinary traffic, all ruts should be filled as soon as formed, by the use of a garden rake,

and all saucer-like depressions should be filled by shoveling in fresh gravel. The cost of filling ruts and depressions will be more than saved in future repairs, and besides a much better road will be the result.

After one layer has been thoroughly consolidated add a second. and so on until the desired depth is reached. The first layer may be the poorer gravel, the best being reserved for the top. All the layers should be added in time to get well packed before the rains and frosts of winter soften the road-bed.

When finished the gravel should be deepest at the center and taper off to the sides. It is immaterial whether the first layer is the widest or the narrowest—there is a little advantage either way. The depth necessary will depend upon the nature of the soil, the quality of the gravel, the amount of travel, the maximum weight per wheel, and the care given to maintenance; but under ordinary conditions, a depth of 8 or 10 inches of compacted gravel at the center is sufficient. The width should vary with the amount of travel, but for a country road a depth of 6 inches at 4 or 5 feet from the center is sufficient.

Fig. 43 shows the dimensions required in good practice.

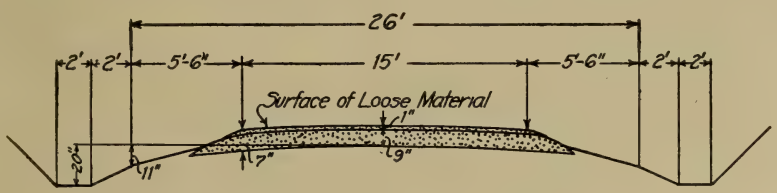

FIG. 43.—CROSS SECTION OF GRAVEL ROAD. SURFACE CONSTRUCTION.

For data on the width of the actually traveled way on gravel roads, see § 95–96.

299. Trench Construction. In this form of construction, a trench is excavated, 10 or 12 inches deep and of the required width for the reception of the gravel. The bottom of the trench is usually made parallel to the finished road surface by sloping it from the center toward the sides (see § 351). Fig. 44 shows the form when the finished surface is an arc. Fig. 44 is the standard form for state-aid roads in Connecticut, except that the width of the graveled way may be 12, 14, or 16 feet. The crown is $\frac{3}{4}$ inch per foot of distance from side to center, or 6 inches for a 16-foot roadway. There is not much difference whether the road surface is an arc or two planes meeting in the center. The latter is probably a little the better for

country roads, although the former is the more common. Notice that in Fig. 44 the intersection of the road surface with the side slope of the embankment, is rounded off somewhat as recommended in

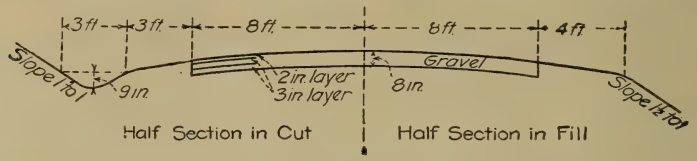

FIG. 44.—CONNECTICUT GRAVEL ROAD. TRENCH CONSTRUCTION.

Fig. 15 and 16, page 85. The exact method of rounding off the corners in Fig. 44 is not specified. The thickness of the layers as shown is after consolidation.

Fig. 45 shows the standard form of construction adopted by the Texas Highway Commission. Notice the wings in Fig. 45.

The bottom of the trench should be rolled to consolidate it and to discover any soft places in the foundation. After rolling, any depressions should be filled and the foundation then re-rolled. The steam roller is better for this purpose than the horse roller, since it is heavier and since the horses' feet do not dig up the subgrade. For a discussion of rollers, see § 378. For precautions to be taken in rolling the subgrade, see § 369.

A layer of 3 or 4, or at most 6, inches of gravel is placed in the trench, and the gravel is harrowed with a tooth harrow, and is then consolidated either by throwing the road open to travel or by rolling. The latter is preferable, since teams in passing each other are liable to break down the edges of the trench and mix the earth with the gravel, and since the wheels are liable to break through the thin layer of gravel—particularly if a wet time intervenes. If the only

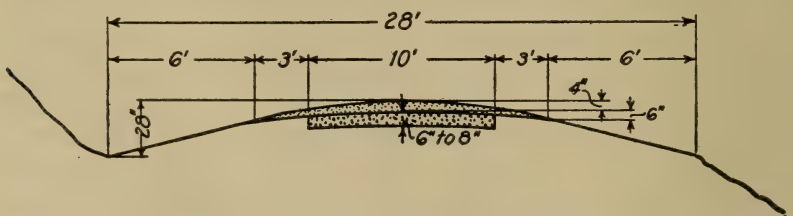

FIG. 45.—TEXAS GRAVEL ROAD. TRENCH CONSTRUCTION.

gravel available contains an excess of large pebbles, they may be used in the lower layer, in which case the layer can not be compacted either by the wheels or by rolling. If the gravel is only slightly

deficient in binding material, it will be impossible to use a heavy roller, since the gravel will push along in front of it.

Additional layers are added as rapidly as the preceding one is compacted, until the desired depth is reached. Before rolling the last layer the earth at the sides of the trench, i. e., the " shoulders " or " wings," should be thoroughly rolled; and then the rolling of the gravel should proceed from the sides toward the center, to prevent the gravel from slipping outward. The gravel will compact much better when damp; but if it is sprinkled, care should be taken that (1) the gravel is not made so wet that the earthy binding material becomes semi-fluid and collects on the surface, and (2) that the subgrade is not unduly softened.

No practical amount of rolling will cause a gravel road to " come down " in the sense that a water-bound macadam road does; that is, a gravel road can not be rolled until the surface is as hard as it will probably be after it has been opened to traffic for a time, since even the heaviest rollers do not give as much pressure as the wheels of heavily loaded wagons. This difference between gravel and water-bound macadam roads is due to the fact that gravel has the binding material uniformly distributed throughout the mass, while with broken stone the binder is spread upon the top and worked in by rolling and sprinkling.

300. Surface vs. Trench Construction. Surface construction is cheaper and seems to be much more common than trench construction. Surface construction is the better, since the depth of the gravel at different distances from the center is approximately proportional to the amount of traffic; while in the trench construction, if the graveled portion is wide the sides are liable not to be much used, and if the graveled portion is narrow passing vehicles are forced upon the earth shoulders. Therefore it appears that surface construction is best for roads having a large amount of traffic. In park drives and streets, the whole width of the roadway is excavated and filled with gravel.

Trench construction is a little more economical of gravel, and is therefore most suitable where gravel is expensive.

301. Earth Road beside the Graveled Way. It is sometimes advocated that there should be two tracks, an earth road for summer travel and a graveled way for winter use. This plan has some advantages and also some disadvantages. When the earth track is dry, it is preferred by most teamsters to the hard gravel road; and the use of the earth roadway decreases the wear on the gravel,

—which is clearly an advantage, for a gravel road like most other things will wear out. On the other hand, if the summer track is immediately adjacent to the hardened way, the earth of the former will become mixed with the gravel of the latter, much to the detriment of the gravel. The chief source of expense in the maintenance of gravel roads is due to the damage done by the mixing of earth from the side of the road with the gravel, thus forming a mixture that will hold water and cause the road to cut up. It has been suggested that the objection to the two tracks could be obviated by constructing a ditch, or sodding a narrow space between the two; but this is impracticable. The two tracks require a wider right-of-way, and therefore for this reason are frequently impossible.

302. For a discussion as to whether the gravel road shall be in the center of the right-of-way or at one side, see § 98.

303. Bottom Course. The gravel usually contains many stones too large to be used in or near the wearing surface, and therefore it is economy to screen the material and lay the larger pebbles in the bottom. Some writers object to using pebbles larger than 1 or $1\frac{1}{2}$ inches in diameter for the bottom course, on the ground that the heaving effect of frost and the vibration due to the passing wheels will cause the larger stones to rise to the surface and the smaller ones to descend—like the materials in a shaken sieve. Unquestionably, if a vehicle is driven over a layer of loose stones of all sizes, the larger ones will tilt up when the weight comes upon them and the smaller ones will roll down into the space made vacant by such tipping; and by a repetition of this process, the large stones will gradually reach the surface. The heaving action of the frost acts in a similar way. But it does not follow that a layer of coarse stones at the bottom of a gravel road will thus work to the top when the interstices of the gravel above are filled with binding material and all is compacted by traffic or by rolling. Experience has shown that if 2 to 4 inches of the top dressing has suitable binding material, it is extremely improbable that pebbles 2 to $2\frac{1}{2}$ inches in diameter in the bottom course will ever work to the surface.

304. Other materials than coarse pebbles may be used for the lower course. In many localities there are large quantities of coal slack, which is useless as fuel and is too friable for the wearing surface of a road, but which can be used for the bottom course of a gravel road. Coal slack has thus been successfully employed, and is often cheaper than gravel. Blast-furnace slag has also been

used for this purpose. Sometimes broken stone is used for a bottom course; but on account of the expense of breaking, only a stone found already broken in the quarry is suitable for this purpose. A "flake" stone or quarry chips are the forms generally used. The celebrated gravel roads of Central Park, New York City, have a "rubble foundation"—not a Telford foundation (§ 349). The rubble layer is 10 to 12 inches thick, and the gravel 4 to 6 inches after being thoroughly compacted. The stones, none of which exceeded 9 inches in greatest dimensions, were dumped upon the subgrade from carts and "evenly adjusted by a little labor of the hand."

305. Screening the Gravel. As a rule gravel should be screened to exclude that which is too fine, and also to insure an even distribution of the fine and coarse material when placed upon the road. Where a small amount of gravel is required, the ordinary stationary inclined screen is used, the gravel being thrown against it with a shovel; but where a considerable amount is required, it is much cheaper to use a rotary screen driven by power.

If the gravel contains a considerable quantity of stones more than $2\frac{1}{2}$ or 3 inches in diameter, a stone crusher can be profitably employed, in which case it may be economical to use an elevator, rotary screen, and elevated storage bins, and to put all of the gravel through the crusher, rotary screen, and storage bin (see Fig. 62, page 205).

Under favorable circumstances, the cost per cubic yard of screening by hand will be about an hour's wages for a man for each time the material is handled with a shovel; while with the rotary screen, it can be screened to three sizes and be placed in elevated bins for the same amount.

306. The Michigan State Highway Department, which builds many good gravel roads, requires the use of a rotary screen not less than 9 feet long and 30 inches in diameter, divided into three sections having perforations 3, 2, and $\frac{3}{4}$ inches in diameter. The Department divides road-building gravel into two classes as follows: The best contains at least 60 per cent of material passing a $2\frac{1}{2}$-inch screen and caught on a $\frac{1}{8}$-inch screen; and the second class contains at least 40 per cent caught between these screens. The Department limits the clay binder to 10 per cent of the entire mass.

The specifications of the American Society for Municipal Improvements for 1916 divide mixtures of gravel, sand, and clay as follows: No. 1 contains 60 to 75 per cent caught between the $1\frac{1}{2}$-inch

and the $\frac{1}{4}$-inch screen, and of this portion from 25 to 75 per cent shall be retained on the $\frac{3}{4}$-inch screen, and of the portion passing the $\frac{1}{4}$-inch screen from 65 to 85 per cent shall be retained on the 200-mesh sieve. No. 2 contains 60 to 75 per cent caught between the $2\frac{1}{2}$-inch and the $\frac{1}{4}$-inch screen, and of this portion from 25 to 75 per cent shall be retained on the 1-inch screen, and of the portion passing the $\frac{1}{4}$-inch screen 65 to 85 per cent shall be retained on the 200-mesh sieve. No. 2 is to be used for the two lower courses of the road, and No. 1 for the top course.

307. HAULING THE GRAVEL. Gravel is usually obtained from pits, and is generally overlaid with more or less earth, which should be entirely removed before beginning to haul the gravel. Not infrequently this earthy material is allowed to tumble into the pit and mix with the gravel, greatly to the detriment of the finished road.

The loading of the gravel can be greatly facilitated by using a board platform 8 to 10 feet long and 4 to 6 feet wide. This platform is placed against the bottom of the bank in such a manner that when the gravel above is dislodged it falls upon the platform, from which it is easily shoveled into the wagon. Often the platform can be supported upon legs at a height above the top of the wagon, and the gravel can be simply pushed off into the wagon with the shovel. Sometimes the circumstances justify the use of a drag scraper (§ 150)—drawn by a horse attached to a cable passing through a block—to drag the gravel to the edge of the platform, whence it drops into the wagon; and sometimes, if a large quantity is to be loaded and a large number of teams are engaged in the hauling, the wagons can be loaded with a trap—an elevated platform upon which the gravel is hauled with a drag or a wheel scraper, and through which it drops into the wagon below.

308. MEASURING THE GRAVEL. When gravel roads are built by public officials, the gravel is usually measured in the pit or in the wagon. The former is the better practice, since it is more definite. When the road is built by contract, the gravel is measured (1) in the wagons, or (2) loose in the road by means of gage boards, or (3) compacted in the road by means of established grades. The first or second method is generally used with surface construction, and the third with trench construction. With the last, it is customary to require that the finished surface shall conform to an established grade; and consequently a considerable quantity of gravel is liable to be forced into the subgrade,—particularly if the earth foundation is made to conform to the grade established for it. The specifications

for state-aid roads in New Jersey specify that "the contractor is to place sufficient gravel on the road to allow it to shrink 33 per cent in rolling and settling." Loose gravel with clay or loam binder will shrink 12 to 15 per cent in rolling, and gravel in which the binder is produced by crushing part of the material will shrink still more—possibly twice as much; the above specifications provide, therefore, for the possibility of forcing 18 to 21 per cent of the gravel into the subgrade.

If it is expected that part of the gravel may be forced into the soil, the subgrade may be left a little higher than the established grade; and then the addition of the stipulated amount of gravel will bring the finished surface to the specified grade. Or, a thin layer of sand on the subgrade will sometimes prevent the gravel from being forced into the soil. For a further discussion of this subject, see § 377.

309. Cost. The cost of gravel roads varies greatly with the form of construction, the cost of gravel, the amount of grading and drainage required, the width and thickness of the gravel, etc. An average depth of 1 foot over a width of 13½ feet requires half a cubic yard per linear foot of road, or 2,640 cubic yards per mile. The gravel usually costs from 5 to 10 cents per cubic yard stripped in the bank. The cost of loading will vary from 5 to 10 cents per cubic yard, not including the time lost by the team in waiting for a load. Setting gage plank, leveling, etc., may cost from 2 to 10 cents per cubic yard. The cost of hauling varies materially with the time of year (see § 4), and including the time lost in loading and unloading, will usually be at least 15 cents per cubic yard (about 1½ tons) per mile and seldom more than 30 cents—the former when done by farmers in the slack season and the latter when done by teamsters. For a haul of 1 mile the total cost in place is 40 to 50 cents per cubic yard.

310. Reports from forty-four counties in Indiana show that the total cost of construction of gravel roads in that state varies from $800 to $3,500 per mile; and except in a few counties, the cost varies from $1,000 to $2,500, and is generally from $1,000 to $2,000. The cost varies with the distance about as follows: when the gravel is hauled 1 mile, the total cost of the road is $1,000 per mile; when the haul is 2 miles, $1,250 per mile; when the haul is 3 miles, $1,500 per mile; when the haul is 4 miles, $1,750 per mile; and if 5 miles, $2,000 per mile. Numerous data from Ohio and Illinois seem to show that the above prices are fairly representative.

In Missouri in 1912 one-course gravel roads 10 feet wide cost $800 to $1,800 per mile, and 15 feet wide from $1,500 to $2,500, exclusive of grading, drainage, culverts, interest, and profits.

In Michigan in 1913 the average cost of 68 miles of state-aid gravel roads was as follows:

Items.	Average Per Mile.	Cost Per Sq. Yd.
Shaping and draining	$455.46	$0.086
Gravel, loading and hauling, 1,649 cu. yd.	247.34	0.046
Culverts, etc.	71.93	0.013
Surfacing	1 661.85	0.316
Total	$2 436.58	$0.460

311. Economic Value of a Gravel Surface. The value to a community of covering an earth road with gravel is a subject the discussion of which leads different persons to widely different conclusions, depending upon the point of view and upon the data assumed.

The advantage of a gravel surface over one of earth is that the hard and impermeable surface of the former is equally good at all seasons of the year. The financial value of a road which is good at all seasons of the year varies greatly with the locality and the occupation of those who use it. Near a large city such roads are nearly indispensable to dairymen, fruit growers, and truck farmers; but permanently hard roads are not of great financial advantage to grain growers and stock raisers, except in the immediate vicinity of a large city. A road which is uniformly good at all seasons of the year is of some economic advantage to a farming community, since it permits hauling to be done at times when other work is impossible, and since it makes possible the marketing of commodities when the price is most favorable. It is impossible to compute the money value of these factors; but, in general, it is not very great (see § 4–7). The chief advantage of a road good at all seasons of the year is its effect upon the social life of the rural district (§ 1–3).

The amount of a load than can be hauled on an earth road is often determined by the grades rather than by the nature of the surface; and unless the grades are light, the maximum load for a gravel road is not much greater than that for a dry earth road. Therefore, before adding a gravel surface to an earth road, the gradients should be carefully studied with a view of deriving the

TABLE 26

Effect of Travel on Different Road Surfaces 15 Feet Wide

Col. Wm. D. Sohier, Chairman Mass. Highway Commission, at Third American Good Roads Congress, Cincinnati, Dec. 13, 1912

Ref. No.	Character of Road Surface.	Character and Amount of Travel.			
		Light Teams per Day.	Heavy Loads, 1-horse, per Day.	Heavy Loads, 2-horse or more, per Day.	Automobiles, per Day.
1	*Gravel:* A good one will wear reasonably well and be economical with	50 to 75	25 to 30	10 to 12	100 to 150
2	It will need to be treated with oil with	.....	.....	.....	over 150
3	If fairly good, should be treated with one half gallon of hot or cold heavy oil annually with	75 to 100	30 to 50	20	500 to 700
4	*Water-bound Macadam:* Will stand with	100 to 150	175 to 200	60 to 80	*
5	A dust preventative will be serviceable with	.....	.....	.....	50 to 100
6	Will stand, but stones wear some with	.....	.....	.....	300 to 500
7	A hot-oil blanket coat will be economical with	250 to 300	75 to 100	25 to 30	†
8	Will crumble and perhaps fail with (if narrow-tired)	100	50		
9	With a good coat of tar will stand with	30 to 50	25 to 30	10 to 15	1800

* Not over 75 at high speed.

† 1,400, and more if the teams are fewer. Will stand at least 50 motor trucks.

utmost benefit of the improved surface by securing easy ruling grades (see § 74).

312. The cost of the improvement is the sum of (1) the annual interest on the cost of construction, (2) the excess of the annual cost of maintaining the gravel road over that of maintaining the earth road, and (3) the annual payment necessary to accumulate a fund sufficient to make periodic repairs, i. e., to add a new surface at intervals. The money spent in road improvements is to be considered as an investment which will return annual interest in the reduced cost of transportation and in the greater freedom of traffic and social intercourse.

313. DURABILITY. On account of the low first cost of the gravel, and the fact that reasonably good gravel roads can be built without any investment of money in rollers, crushers, and other costly machinery, they are well suited to light traffic roads, to residence streets in small cities, and to park drives. A gravel road well built of good material is excellent for automobiles, and will safely carry a considerable number daily—see Table 26, page 177.

314. SPECIFICATIONS. The American Society of Municipal Improvements publishes standard specifications for the material and workmanship of gravel roads. The specifications are modified from time to time as is necessary to keep them up to date. Printed copies may be had of the secretary for a nominal sum.

The various State Highway Departments also publish standard specifications

ART. 3. MAINTENANCE

316. There are more miles of gravel roads in this country than of any other type of improved roads; and therefore the proper maintenance of these roads is an important matter. If properly constructed and reasonably maintained, a gravel road is quite satisfactory except under very heavy travel.

The proper care of side ditches, culverts, shoulders, and the surface has been considered in the discussion on earth roads—Art. 2, Chapter III;—and all that has been said there applies equally well to gravel roads. The maintenance of a gravel road is more important than that of an earth road, because more is rightly expected of the former than of the latter; and since the gravel road represents a greater investment, neglect may result in greater damage.

317. DESTRUCTIVE AGENTS. The destructive agents are the same for gravel as for earth roads (see § 198–204), except that for

gravel roads a gradient is an element of destruction whose importance varies with its steepness. Horses in drawing a load up a hill or in holding back a load in coming down, are liable to displace pebbles with the calks of their shoes, and after the first stone is displaced it is easier to loosen others. The locking of the wheel, until it slides in going down hill, is also hard on a gravel road.

Grades have a further disadvantage. Automobiles are likely to speed up at the bottom of the grade so as to reach the top at a fair velocity, and the sudden acceleration of the speed is likely to dislodge pebbles and cause the road to ravel.

318. The Methcd of Maintenance. The three methods of maintenance employed in caring for earth roads (§ 222–26) are also employed for gravel roads. Since gravel roads represent a greater investment, and since more is expected of them, it is desirable that they shall be cared for under the patrol system, that is, the system of continuous maintenance.

When a gravel road is first thrown open to traffic, it should be carefully watched and all incipient ruts and depression should be filled as soon as formed, either by raking in gravel from the sides of the depression or by adding fresh gravel—in the earlier stages of this work the former is the better, and in the later stages the latter is necessary. The new gravel should be finer and contain more binding material than that employed in the original construction. If the depression is very shallow, it is wise to roughen the surface with a garden rake before adding the new material. It is important that ruts and shallow holes should be filled as soon as they appear, for they will hold water, which will soften the gravel bed and cause the road to wear rapidly. At, say, every $\frac{1}{8}$ mile a small pile of gravel should be stored to be used in filling depressions.

If the road surface becomes muddy when wet, there is an excess of clay binder; and therefore a thin layer of coarse clean sand or fine clean gravel, preferably the latter, should be added. On the other hand, if the surface shows a tendency to disintegrate or ravel, there is not enough binder; and therefore a layer of clay should be added and harrowed into the gravel. However, if the surface does not at once set up, it should not be concluded that there is not enough binder, for a road that binds quickly is likely to cut up badly, particularly when wet.

During this stage, all loose stones should be removed from the roadway, both for the comfort of travelers and the good of the road.

After the gravel has become thoroughly consolidated, i. e., after

the wheels no longer make even shallow ruts, the only care the road is likely to need for several years is to keep the side ditches and culverts free from weeds and floating trash, and to attend to the drainage of the surface when the snow is melting (§ 219).

After a time the gravel will work out to the sides of the road too far, and the center will wear hollow. It will then be necessary to use a scraping grader (§ 155–56) to push the gravel back to the center. In doing this care should be taken not to scrape up the earth with the gravel. A good time to use the grader is just after a rain, when the road is soft and easily scraped, and when the gravel scraped to the center is in the best condition to pack again. The road should never be allowed to wear so hollow in the center as to interfere with the flow of water from the surface to the side ditches.

319. Sprinkling. A gravel road with clay binder needs a little moisture to hold it together, since the clay shrinks and cracks under excessive drought, loses its binding power, and permits the road to break to pieces. Under such circumstances a sprinkling with water is a means of preserving the road from serious damage, although on account of the expense this is seldom done except on park drives.

320. Re-Surfacing. It will finally be necessary to repair the surface by adding a coating of new gravel. For this purpose the size of the largest pebbles should vary with the thickness of the coat. It is usual to put the gravel on by making two or three dumps of a wagon load, i. e., by stretching a cubic yard over 15 to 25 linear feet, according to the thickness of layer required, and spreading the gravel just a little wider than the wagon track. Traffic will spread it still wider, and also pack it.

In making repairs, it is better to apply a thin coat often than a thicker coat less frequently, since a thick coating does not pack well. A layer of 2 inches of gravel is better than more—unless on a spot that has cut through.

321. Cost. The cost of maintenance varies with the climate, the amount and nature of the traffic, the quality of the gravel, etc. Data from Indiana and Ohio show that it varies from $40 to $100 per mile per annum—the former where the traffic is light, the gravel good, and the snow light; and the latter where the traffic is heavy, the gravel poor, and the snow heavy. In New Hampshire the cost is $20 to $100, usually, $20 to $50 per mile per year exclusive of re-surfacing; or including re-surfacing, $150 to $300 per mile per year

for all expense.* In Vermont the average cost of maintaining 175 miles in 1912 varied from $10.97 to $32.33, the average being $20.71.

ART. 4. DUST PALLIATIVES

323. The surfaces of gravel roads are treated for two distinct purposes,—to lay the dust and to bind the surface materials. The agents that accomplish the first are called dust palliatives; and those that secure the second are called road binders, protective coatings, or bituminous carpets. Only the first will be considered here.

324. DUST PREVENTIVES. The suppression of the dust from an earth road is in the interests of the people using the road or residing adjacent to it; but the prevention of dust on a gravel road is important not only to the interests of those using the road or living near it, but also to the very life of the road itself. The simplest materials used for this purpose are: Fresh water, salt water, deliquescent salts, proprietary compounds, oil, and tar. The two latter are the most common, and are used primarily as road binders, although they incidentally prevent the binder of the gravel from being blown away as dust.

325. Sprinkling with Fresh Water. This is the simplest method of preventing dust. Sprinkling a gravel road with water not only suppresses the dust, but prevents the disintegration of the surface by raveling (see § 397). The water should be applied in a fine spray, and in such quantities as not to run in streams on the surface; that is, several light sprinklings are better than a single flooding. If sprinkled too heavily or too often, the road is softened and breaks up easily.

Reliable and definite data concerning the cost of sprinkling are rather meager. Dust may usually be kept down on a gravel road carrying a moderate amount of heavy travel, by sprinkling, for about 2 to 3 cents per square yard per annum.

326. Sprinkling with Sea Water. This is a simple remedy, but obviously is applicable only to roads located near the sea coast. Sea water is more effective in laying dust than fresh water owing to cer-

* From an instructive account of the patrol system of maintenance employed by the New Hampshire Highway Department, in *Engineering News*, Vol. 74 (1915), p. 1110. For an article explaining the use of gasoline motor trucks and trailers in maintaining gravel roads in Alabama and giving data on the cost of the work, see *Engineering Record*, Vol. 74 (1916), p. 73–74.

tain deliquescent salts which it contains; but the presence in the sea water of salts not possessing hygroscopic properties causes disagreeable and destructive mud in wet weather, and renders this form of treatment rather unsatisfactory.

327. Moistening with Deliquescent Salts. Solutions of water and various deliquescent salts have been used to moisten the surface of roads to prevent dust. The effect of these solutions is more lasting than that of fresh water alone, and they are easily applied by the ordinary sprinkling wagon. However, some difficulty is encountered in obtaining a solution of constant strength, and its cost is considerable.

Among the most common of these salts is calcium chloride, which may be obtained commercially in a granular condition or in a concentrated solution. The granular salt may be applied with an ordinary agricultural drill. When applied in granular form about three fourths of a pound per square yard is used for the first application, and slightly less for succeeding ones. When applied in liquid form, a 15 per cent solution is ordinarily used for the first application, and for successive applications an 8 or 10 per cent solution is employed. Of course, such salts are not suitable in arid or semi-arid regions, since there is but little moisture in the air to be absorbed; nor in an extremely humid climate, since the salt is likely to be washed away by the rains. Calcium chloride is odorless and clean, but has no permanent effects upon the road. It may cause soreness in horses' feet, if used in quantities much in excess of those stated above.

328. Sprinkling with Proprietary Compounds. There are a number of proprietary dust-laying compounds upon the market. Most of them consist of deliquescent salts dissolved in water, and some consist of by-products from manufacturing. The names of a few of the first class are: Aconia, calcite, and panscale. Several of them seem to be no more efficient than calcium chloride, but are considerably more expensive.

329. Sprinkling with Light Oil. The dust of a gravel road may be laid by sprinkling it with oil much as was described for an earth road (§ 236–39); but it is usually more economical to apply a protective coating or bituminous carpet (Art. 1 and 2 of Chapter IX) which not only prevents to a certain degree the formation of dust, but protects the surface of the road.

Oil as a dust layer was used chiefly on park drives and suburban roads, but has been abandoned where there is any considerable amount of automobile travel. The following account from the pre-

vious edition of this volume describes the former practice in Washington, D. C.

330. *Practice in Washington, D. C.* The city of Washington, D. C., formerly sprinkled the gravel park drives with the light asphaltic oil described in § 552. The following is a description of the method then employed in applying the oil.*

"All ruts and holes in the surface of the road are first repaired by cleaning out the cavity, filling it with coarse stone which is covered with a coating of hot, heavy, asphaltic oil, then sprinkling a light coat of screenings over the oil, and finally compacting the patch by ramming. When all holes have been thus repaired, the surface of the road is thoroughly cleaned with rattan brooms, care being taken to remove all loose materials and caked dirt or dust so that the stone forming the wearing surface of the road shall be exposed and clean.

"When the road is entirely free from moisture, and during warm dry weather, if possible, a light asphaltic oil is spread (without being heated) by means of special sprinkling wagons. One third to one half gallon of oil to the square yard usually forms the first application. To allow it to penetrate into the surface, the road is closed to traffic at least 48 hours after the first application.

"At the end of this time the surface of the road is covered with a thin coating of clean, coarse, sharp sand or stone screenings, free from dust; and is then rolled and traffic allowed to go over it. A cubic yard of sand or screenings usually covers from 75 to 125 square yards of road surface.

"The oiling described above keeps the surface in excellent condition for a year. It is never dusty, and is muddy for only a few hours after a heavy thaw when the skid-chains of automobiles tear up the surface. The subsequent passage of automobiles without chains soon irons out the roadway. At the end of the year the surface of the road is again thoroughly cleaned, from $\frac{1}{6}$ to $\frac{1}{4}$ gallon of oil to the square yard under normal conditions being spread over it, and the road closed for 48 hours and covered with sand or screenings as before. This treatment is continued from year to year."

"The cost for the first application, from 2.8 to 4.6 cents per square yard; and for the second application from 1.3 to 2.8 cents per square yard."

* Paper by Col. Spencer Cosby, U. S. Army, in Charge of Buildings and Grounds, Washington, D. C., presented before Section D of the American Association for the Advancement of Science, on Dec. 29, 1911.

331. The amount of oil applied is often considerably greater than that employed in Washington, D. C., as mentioned above, being from 0.3 to 0.4 gallon per square yard, in which case the total cost of material and labor is from 4.0 to 7.0 cents per square yard. When the quantity required is as great as this, it is probable that the expense is not justifiable, since instead of spending the larger sum for a light oil, it is more economical to spend a little greater amount for a heavier oil or for a stronger binding material, and construct a more durable protective coating (see § 583).

CHAPTER VI

WATER-BOUND MACADAM ROADS

334. Throughout the entire nineteenth century a road built by placing small fragments of broken stone on the ground and compacting them into a solid mass by rolling or by travel was called a macadam road, after John Loudon MacAdam (1756–1836), a famous English builder of broken-stone roads and one of the first to build such roads. The broken stone is called macadam, and the work of construction macadamizing.

A broken-stone road is sometimes called a telford road after Thomas Telford (1757–1834), a famous English engineer; but the term telford is usually, and appropriately, restricted to a particular form of the foundation of a broken-stone road (§ 349).

The fragments of stone in the road referred to above were held together by the cementing power of the dust of the stone; but the use of the automobile has shown the desirability of a broken-stone road having a binder stronger than stone dust; and this led in the early years of the twentieth century to the introduction of a new type of broken-stone road—one bound with a bituminous cement, such as tar or asphalt. Such a road is called a bituminous macadam road; and consequently the broken-stone road having a stone-dust binder is now called a water-bound macadam road.

For more than a hundred years the water-bound macadam was a leading form of improved road all over the world, and even now it is exceeded in mileage only by earth and gravel roads; but, since the early years of this century, it is much less frequently built than formerly. It is used now only in rural roads having comparatively little motor-driven travel and on residence streets having but little through travel. In some particulars the water-bound macadam road will be discussed a little more fully than its individual merits may warrant, because many of the principles of its construction are applicable to bituminous roads, which are becoming increasingly important.

Art. 1. The Stone

335. Requisites for Road Stone. The principal requisites of a material for a water-bound macadam road are hardness, toughness, cementing or binding power, and resistance to the weather. Usually any stone that is hard and tough will resist the weather reasonably well; but shales and slates, though hard and tough when first quarried, often disintegrate when exposed to the weather. The material for a road surface should also be uniform in quality or the surface will wear unevenly; and the depressions which occur where the material is comparatively soft will hold water, thus softening the road-bed and occasioning damage difficult to repair.

336. Hardness and Toughness. These two qualities are closely related. Hardness is that property of a solid which renders it difficult to displace its parts among themselves; while toughness enables the parts to yield somewhat without being separated or broken. For road purposes, hardness is the power possessed by a rock to resist the rubbing or the abrasive action of wheels and horses' feet; while toughness is the adhesion between particles of a rock which gives it power to resist fracture when subjected to blows. A stone may be hard and brittle, and be quickly pounded to pieces in the road, as quartz; or it may have a high crushing strength and yet be deficient in toughness, and grind away speedily under the abrasion of traffic, as some varieties of sandstones. A road metal should have enough resistance to crushing to support the load brought upon it by the wheels, and enough toughness to prevent its being readily ground into powder. A large part of the fine material is inevitably swept away by the rains and winds, or is removed by scrapers to keep the road in good condition during wet weather; and therefore it is important that the fragments should be tough enough not to be unduly pulverized by travel. Toughness is incompatible with a high degree of hardness, and in a measure makes up for a deficiency in resistance to crushing. Hardness could be measured by the resistance offered by a rock to the grinding of an emery wheel; and toughness would be measured by the resistance to fracture when struck with a hammer.

337. Cementing or Binding Power. Binding power is the property possessed by rock dust to act as a cement between the coarser fragments composing a stone road. This property is of the highest value, for the strength of the binder determines the resistance of the

road to the wear and tear of travel more than does the strength of the fragments themselves. It is possessed in a very much higher degree by some varieties of rocks than by others, and its absence is so pronounced in some varieties that they can not be made to compact under the roller or under traffic without the addition of some cementing agent.

338. Methods of Testing Stone. There are two methods of determining the qualities of a stone for road-building purposes: (1) by using the stone in the road and keeping an account of the cost of repairs over a series of years, or (2) by laboratory experiments. The first is uncertain owing to the variations in climatic conditions, and in the amount and nature of the traffic, etc.; and would be very expensive and take a long time. In the second method of testing, it is difficult to duplicate in the laboratory the conditions of actual service; but nevertheless much valuable information may thus be obtained at a moderate expense and in a comparatively short time.

Systematic laboratory tests of road metal are of comparatively recent origin, and may be said to have been started about 1880 by the French governmental engineers, who have made extensive use of this method in determining the quality of the rock used in contract work and in selecting new quarries. Only a little such laboratory work has been done in England and Germany. From 1894 to 1899 the Massachusetts Highway Commission conducted a series of tests of road-making materials, and developed new and important methods of testing, and deduced much valuable information.

339. Since the latter date the U. S. Office of Public Roads and Rural Engineering has conducted extensive laboratory tests of the road-building stones. Bulletin No. 370 (1916) describes the methods employed and gives the results obtained for 3,650 samples from forty states and three foreign countries. The Laboratory tests road materials for public officials without cost; and also gives advice as to the value of the material for road-building purposes.

340. The principal tests applied to stone for water-bound macadam roads will be very briefly described.

341. Hardness Test. This test determines the hardness of the stone; and virtually consists in measuring the amount ground off under certain conditions. The loss in the above tests varied from 1.0 to 32.8 per cent, usually from 2 to 10. The test is made with the Dorry machine.

342. Toughness Test. This test is to determine the resistance to

impact. It is made by finding the number of hammer-like blows required to break a cylindrical specimen. The results range from 3 to 43, about half of the materials requiring from 10 to 20 blows. The test is made with the Page impact machine.

343. Abrasion Test. The results of this test depend upon both hardness and the resistance to abrasion. Fragments of the stone are rotated in a cylinder inclined to the axis of rotation, and the amount worn off is determined. The result is expressed either in per cent of wear or in the arbitrary French coefficient of wear, which equals 40 divided by the per cent of wear. The latter is in more common use. The French coefficient of wear for the test referred to in § 339 ranges from 1.4 to 41.7, usually from 10 to 30. The test is made with a Deval machine.

344. Cementation Test. This test determines the binding power or cementing value of the stone dust to hold together the coarser fragments of a water-bound macadam road. This is the most important quality of a stone for such a road. The test is made by placing small fragments of stone and water in a ball mill and grinding them to a stiff paste, which is then moulded into a briquette under heavy pressure. The briquette is dried and tested in an impact machine to determine the number of blows required to break it. The results range from 0 to over 500. Values below 10 are called low; from 10 to 25, fair; from 25 to 75, good; from 75 to 100, very good; and above 100, excellent. The results for a few stones are as follows:

Name.	Max.	Min.	Name.	Max.	Min.
Andesite	500+	9	Gravel	500	3
Basalt	500+	2	Limestone	500	9
Chert	500+	2	Marble	85	10
Conglomerate	500+	20	Quartzite	45	0
Diabase	500+	2	Sandstone	500+	1
Diorite	148	5	Shale	367	28
Granite	255	2	Slate	500+	1

345. Conclusion. The principal rocks used for water-bound macadam roads are traps (a popular term which includes diabase, diorite, and several other igneous rocks), granites, and limestones. Their value for road-building purposes is in the order named. In the Eastern States the traps are the ones most used, in the Mississippi Valley limestone is the most common.

For information concerning the road-building materials of the

United States, see Preliminary Report on the Geology of the Common Roads of the United States, by Nathaniel Southgate Shaler, in U. S. Geological Survey, Fifteenth Annual Report, 1893–94, p. 255–306.

ART. 2. CONSTRUCTION

347. The principles of construction for earth roads apply also to the construction of the subgrade for broken-stone roads (see Art. 1, Chapter III). The drainage of the foundation by tile drains and side ditches should not be neglected (see § 114–24 and § 125–28).

348. FORMS OF CONSTRUCTION. With reference to the method of preparing the subgrade to receive the stone, there are two forms of construction—surface construction and trench construction. The surface construction consists simply in placing a layer of broken stone upon the earth road and leaving it to be compacted by travel. In the West many miles of road are constructed on this plan with limestone. As a rule this material readily pulverizes under the traffic, and the powder cements well; consequently the road soon binds together. Such roads are not first class, but they give good returns on their cost. On account of the simplicity of the construction, this form will not be considered further.

The trench construction consists in excavating a trench of the required width and depth, and depositing the broken stone in it.

349. With reference to the lower course of stone there are two systems of construction,—the macadam and the telford (§ 334). The macadam road consists of two or more layers of crushed stone, its distinguishing characteristic being that the lower course of crushed stone is placed directly upon the earth road-bed. The telford road consists of a foundation or pavement of rough stone blocks set upon the road-bed, covered with one or more layers of crushed stone, the distinguishing feature being the paved foundation.

350. Telford vs. Macadam Roads. Each of these systems has its earnest advocates who contend for its exclusive use.

The most important claims of the advocates of the telford construction are (1) that the open foundation is necessary for drainage; (2) that the sub-pavement is necessary on soft or poorly drained soil to prevent the small fragments of broken stone from working down into the soil and the soil from working up into the stone; and (3) that the telford is the cheaper, since the expense of crushing is saved.

The most important claims of the advocates of the macadam system are: (1) that the drainage afforded by the telford construc-

tion is no better than that with the macadam construction; (2) that on any well drained soil there is no tendency of the stone to work down or of the soil to work up; (3) that tile drainage and macadam construction are cheaper than the telford system; and (4) that since the introduction of the machine rock-breaker, it is cheaper to crush the stone and lay the macadam foundation than to place the telford.

The view taken by different road builders in this matter is probably largely due to the conditions in the vicinity in which they have worked and to the skill with which the two systems have been applied in work which has come under their observation. The foundation which is proper in a given case is determined by the nature and condition of the soil upon which it is constructed. If the road-bed is thoroughly drained and is composed of material which will not readily soften, there will be no need of a telford foundation. If, on the other hand, the soil is retentive of moisture and can not be thoroughly drained, it may be necessary to provide a foundation which will prevent the soil from working up into the stone and the road metal from working down into the soil.

To MacAdam is due the credit of discovering the supporting power of a layer of comparatively small angular fragments of stone.

351. Forms of the Subgrade. The finished surface of the road should have sufficient crown to shed the rain water into the side ditches. There are in common use two methods of securing this crown. In one the earth surface is made level, and the slope is given by a greater thickness of metaling at the center than at the sides; in the other, the slope or camber is given to the earth bed, and the metal has a uniform thickness. The advocates of the first system say that there is more wear at the center than at the sides, and that consequently the metaling should be thicker at the center. Those in favor of the uniform thickness say that as the pressure on the earth is practically the same at the sides as at the center, the thickness should be uniform, since the principal object of the layer of stone is to distribute the concentrated pressure of the wheel over a greater surface of the earth bed. Both forms of construction are in common use, although the preference seems to be slightly in favor of making the subgrade parallel to the finished road-surface and the stone of uniform thickness. A level subgrade is slightly cheaper to form.

Fig. 46 shows a cross section of the celebrated Shrewsbury and Holyhead road in the west of England, built by Telford in 1815. The construction of this road, which formed a link in

the direct line of communication between England and Ireland, was made a national undertaking, and resulted in what was at that

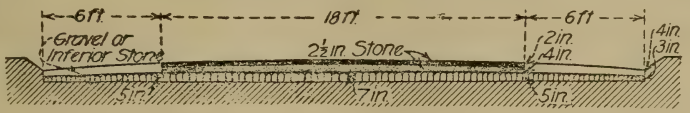

FIG. 46.—TELFORD'S SHREWSBURY AND HOLYHEAD ROAD.

time one of the finest pieces of road construction in the world. Notice that the subgrade is flat.

Fig. 47 shows a modern telford road as built in New Jersey.

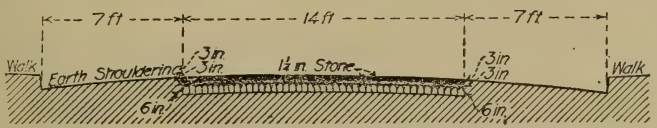

FIG. 47.—MODERN TELFORD ROAD AS BUILT IN NEW JERSEY.

Notice that the base of the foundation is parallel to the surface of the finished road.

Compare the above with Fig. 51–56, pages 197–99.

352. WIDTH. For a discussion of the principles governing the the width of the improved way, and also whether it shall be in the center or at the side of the wheelway, see § 95–98.

353. Shoulders. The discussion referred to above deals only with the width of the paved portion; but there should be an additional width of earth sufficient to keep the broken stone in place, particularly while being rolled. This strip of earth is usually called a shoulder, but sometimes and improperly a wing (see § 364). The proper width of the shoulder will depend upon the soil, the climate, and the amount of rolling it receives. Usually 2 or 3 feet is sufficient, although 5 to 7 feet is frequently provided—see Fig. 47. The Swiss road shown in Fig. 53, page 198, has a shoulder of only 18 inches. An excessive width of shoulder adds greatly to the cost of the road when in excavation or on embankment. The surface of the shoulder should conform to the general curve of the finished roadway. The shoulder serves the double purpose of holding the broken stone in place and of affording room for vehicles to pass each other. To improve the shoulders for the second purpose, they are sometimes covered with a thin coat of gravel to harden the surface. Sand shoulders are speedily hardened by the infiltration of fine stone

dust and dirt washed from the surface of the road. This effect is quite noticeable with coarse sand; and is appreciable even with fine sand.

354. CROWN. The center of the road should be higher than the sides, so that the water from rains may flow rapidly into the side ditches. If originally too flat, the road is soon worn hollow, and the middle becomes a pool if on level ground, or a water course if on an inclination. In the former case the middle of the road is sloppy; and in the latter, the fine material washes away and leaves the larger stones bare. There has been much discussion both as to the proper amount of crown and the exact form of the transverse profile of the roadway.

355. Form of the Crown. Some claim that the upper surface should be curved, and others that it should be two inclined planes meeting at the center of the road and having their angle slightly rounded off. Both forms are in common use; the first is the more common, but apparently the latter is the better.

The following objections are urged against the curved profile: 1. The greater slope near the side causes vehicles to seek the center, and consequently the road wears unequally. 2. Owing to the excess of travel at the center, the road soon wears hollow and holds water, which is both unsightly and a damage to the road. 3. The slope is so slight near the center that a small settlement of the subgrade causes a depression of the surface, which holds water.

The only objection to a surface composed of two planes is that the flanks wear hollow and hold water; but this objection has less force than any of the three against the curved profile.

Regularity and evenness of crown is more important than the mathematical form of the cross section. A slight depression becomes very conspicuous when filled with water; and besides the water standing upon the surface softens it and tends to increase the depression. With a little care in filling the low places developed during the rolling, it is possible to build a broken-stone road with an almost mathematically exact crown.

356. Amount of Crown. The proper amount of crown depends chiefly upon the method of making repairs. If new material is added only, say, each second or third time the surface is smoothed up, then the crown should be greater to compensate for future wear; but if new material is added practically continuously, the crown may be considerably smaller. The rate of transverse slope should be smaller on wide than on narrow streets, to prevent the

water from unduly washing the surface near the sides. There should be more crown on steep grades than on flat ones, to throw the water quickly to the side ditch and to prevent it from flowing down the grade on the surface of the road and washing out the binder.

Sometimes wide boulevards, with curved profile and maintained by continuous repairs, have a crown of one sixtieth of the width, or a rise of 0.4 inch per foot from side to center, or an average slope of 1 in 30. The French roads, which have a curved profile and are maintained by the system of continuous repairs, have a crown of one fiftieth of their width, or a rise from side to center of 0.5 inch per foot or a slope of 1 in 25. Many of the better cared for streets and park drives have a crown of one fortieth, or a rise from side to center of 0.6 inch per foot or an average slope of 1 in 20. On the state-aid roads in Massachusetts (narrow roads and continuous repairs), the surface consists of two planes meeting in the center, the transverse slope being $\frac{3}{4}$ inch to a foot or 1 in 16. Broken-stone roads made of soft stone and maintained by periodic repairs frequently have an original crown of one twelfth—an average slope of 1 inch to 1 foot or 1 in 12.

357. With a broken-stone road, the method of making repairs has more weight in determining the amount of the crown than in the case of either an earth road or a gravel road. The earth road is easily and cheaply maintained by what may be called the system of continuous repairs with the road drag, which restores or rather maintains the crown. With a gravel road, when it is necessary to restore the crown by adding more gravel, it is usually sufficient to put on only a thin layer and wait a comparatively short time for travel to consolidate it. With a water-bound macadam road, if the crown or rather the surface is to be perpetually maintained, it is necessary to keep a man upon a short stretch of the road practically all of the time, adding thin patches of stone in first one place and then another, a method so expensive that it is practiced in this country only on park drives, boulevards, etc.; and if the crown is to be restored periodically, it is necessary to add a considerable layer of stone and consolidate it by long continued and expensive rolling and sprinkling, and on account of the expense of this operation and the obstruction to traffic it is customary to lay such a thickness of stone and to give the surface such a crown as not soon to require a repetition of the process. Therefore it happens that broken-stone roads are often built with a crown nearly, if not quite, equal to that of good

earth roads, and with more perhaps than is given to good gravel roads.

358. There is a slight advantage of a very high crown for a broken-stone road, particularly for one that is not frequently cleaned. If the crown is great, the rains will the better wash the surface. Dirt upon the surface is not only unsightly, but is also detrimental since it holds the water and softens the surface. Of course the material washed by rains into the gutter must eventually be removed; but this can be removed more cheaply from the gutter at comparatively long intervals, than from the surface with brooms or scrapers at short intervals. The practice of making a high crown is somewhat common in villages using soft road metal and having earth gutters and only surface drainage.

This advantage of a high crown is less for a country road than for a village street, since the wind usually gets a better sweep at the former than at the latter.

359. Super-elevation on Curves. For a rule for the super-elevation of the road surface on curves, see § 90.

360. THICKNESS. The object of placing a layer of broken stone upon the trackway is to secure (1) a smooth hard surface, (2) a water-tight roof, and (3) a more or less rigid stratum which will distribute the concentrated pressure of the wheel over so great an area of the subgrade that the soil can support the load without indentation. The smoothness and tightness of the surface depends upon the quantity and quality of the binding material (§ 383–87), and the rigidity of the layer depends somewhat upon the binder, but chiefly upon the thickness of the stratum. The supporting power of the subgrade depends upon the nature of the soil and the drainage. Therefore the minimum thickness of broken stone depends upon the nature of the soil, the drainage, the traffic, and the binding material; and the initial thickness depends upon the amount of wear permitted before new material is added. If repairs are continuous, the initial thickness may be the minimum; but if repairs are made periodically, the initial thickness must be equal to the minimum thickness plus the amount allowed for wear. After a road has been worn down 3 inches, it is usually so uneven as to require re-surfacing; and therefore it is uneconomical if the road in this stage is much or any thicker than the minimum required to prevent its breaking through.

There has been much discussion and there is a great difference of opinion as to the proper depth of a broken-stone road. The

depth considered necessary by the most extreme advocates of thick roads has decreased with the introduction of more improved methods of construction—particularly the use of binder and a steam roller,—and as the advantage of thorough underdrainage has been better appreciated. Early in the last century a depth of 18 to 24 inches was frequently considered necessary for heavy traffic, but later it was reduced to 12 or 15 inches, while now 6 inches, or less, is usually considered sufficient.

361. Theoretical Thickness. The concentrated load of a wheel is transmitted through the broken stone to the earth in lines diverging downward, and the wheel may be assumed as resting upon the apex of a cone whose base is upon the earth subgrade. It is not wise to attempt to find a mathematical relation between the load on the wheel and the resulting pressure on the earth, since neither the angle of the cone nor the distribution of the pressure on the base of the cone are known.

The Massachusetts Highway Commission assumes the concentrated load to be uniformly distributed over an area equal to the square of twice the thickness of the layer of crushed stone, which is equivalent to assuming that the sides of the cone make an angle of $48\frac{1}{2}$ degrees with the vertical and that the pressure is uniformly distributed over the base. According to this theory, if t = the thickness of the stone in inches, w = the maximum weight in pounds per wheel, and p = the supporting power of the soil in pounds per square inch, then

$$t = \sqrt{\frac{w}{4p}}. \quad \ldots\ldots\ldots \quad (1)$$

The Commission has applied this formula to roads already constructed to determine the safe bearing power of the soil, and concludes that non-porous soils, drained of ground water, at their worst will support a load of 4 lb. per square inch, and that sand and gravel will safely support 20 lb. per square inch.*

Although the method of arriving at equation (1) is not correct, the manner of deducing the supporting power of the soil in a measure offsets the error, and consequently the formula may be used with some confidence.

362. Actual Thickness. In Massachusetts the thickness for state-aid roads varies from 4 to 16 inches, the standard for crushed

* Massachusetts Highway Commission, Report for 1901, p. 15.

stone with macadam foundation on well-drained sand or gravel being 6 inches, " which appears to be ample for the heaviest traffic."

In New Jersey, on state-aid roads, the depth of stone with macadam foundation varies from 4 to 12 inches, but is generally 6 inches; and the telford roads are from 8 to 12 inches thick, usually 8 inches. Most of the roads have a macadam foundation, the telford being used as a rule only where field stones suitable for a telford foundation are found alongside of the road.

363. The experience at Bridgeport, Conn., has been frequently cited to prove that a comparatively thin road is sufficient. Something like 60 miles of 4-inch macadam roads built in that place gave excellent service even under heavy traffic. The conditions were very favorable for a thin road: (1) the soil was sand or sandy loam, and had fairly good natural drainage; (2) the subgrade was thoroughly rolled with a 15-ton roller; (3) the broken stone was trap, which is hard and durable; (4) the binder was hard and durable, being either stone dust or siliceous sand, and was free from clay or loam; (5) the binder was worked in until the voids in the crushed trap were practically filled, the effect of frost being thus reduced to a minimum and the soil being prevented from working up from below; (6) the stone was thoroughly consolidated with a steam roller of adequate weight; and (7) the roads were maintained by the system of continuous repairs.

The experience at Bridgeport has been repeated at several other places; but such experiences should be regarded as the exception, rather than the rule, since 4-inch roads are adequate only under favorable natural conditions and with the most painstaking construction and careful maintenance. The fact that a very thin road can carry the traffic does not prove that such a road is the most economical, for the increased cost of maintenance may more than counter-balance the decreased cost of construction. The engineer should always attempt to construct economically and adapt his construction to fit the natural conditions.

364. Wings. In the preceding discussion of the thickness of the road metal it has been assumed that the depth was practically uniform; but some engineers, in recognition of the fact that there is less travel nearer the sides than at the center, make the thickness of a strip on each side considerably less than that at the center. The thin strips on the sides are called wings. Fig. 48, a portion of the Swedesboro road in Gloucester County, New Jersey, shows a cross section of this form. This construction is somewhat common in

New Jersey, both with telford and macadam foundations, and has been adopted by the U. S. A. engineers for macadam roads in Porto Rico. The wings are usually 2 or $2\frac{1}{2}$ feet wide. A road with wings

FIG. 48.—NEW JERSEY TELFORD ROAD WITH MACADAM WINGS.

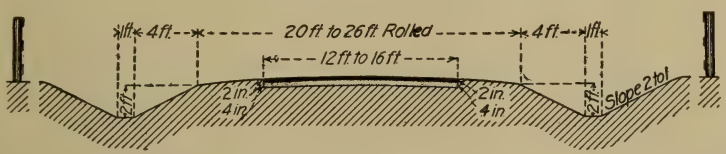

FIG. 49.—STANDARD SECTION FOR NEW YORK STATE-AID ROADS.

is simply a compromise between a narrow thick road and a wide thin one.

365. EXAMPLES OF CROSS SECTIONS. Fig. 46, page 191, shows a cross section of a telford road built under Telford's direction in

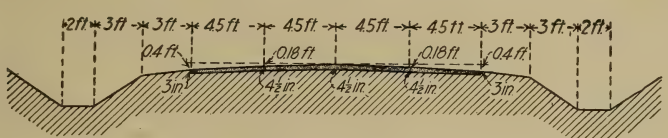

FIG. 50.—GENERAL SECTION OF FLUSHING AND JAMAICA ROAD.

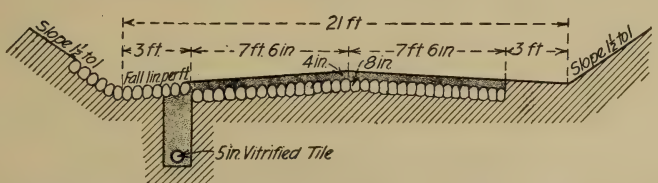

FIG. 51.—STANDARD SECTION IN EXCAVATION FOR MASSACHUSETTS STATE-AID ROADS.

1815. Fig. 47, page 191, shows a New Jersey telford road. Fig. 48 shows a telford road with macadam wings. Fig. 49 shows the standard cross section for state-aid roads in the State of New York. Fig. 50 is a section of a road in Flushing, Long Island, near New York

City. Fig. 51 and 52, are the standard cross sections in excavation and on embankment, respectively, for state-aid roads in Massachu-

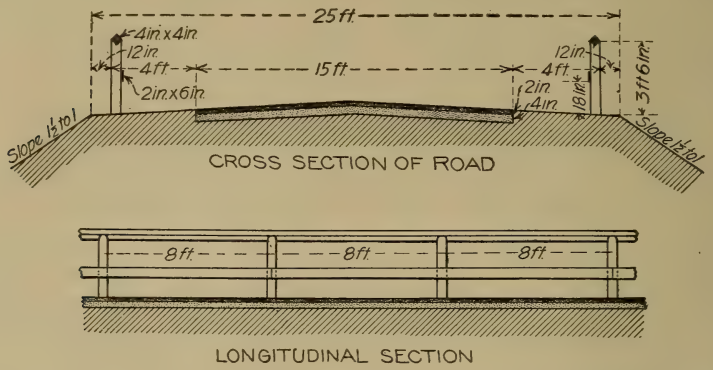

Fig. 52.—Standard Section on Embankment for Massachusetts State-aid Roads.

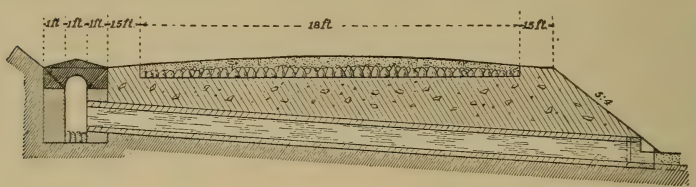

Fig. 53.—Class-II Road, Canton of Bern, Switzerland.

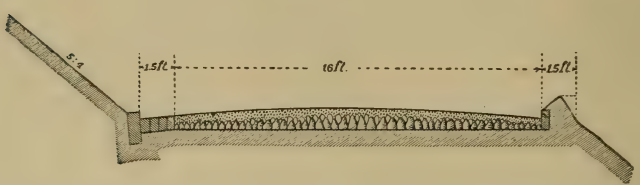

Fig. 54.—Class-III Road, Canton of Bern, Switzerland.

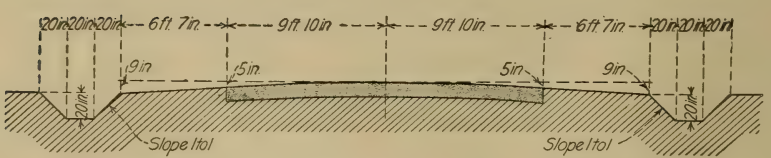

Fig. 55.—Typical Road in Department of Bas-Rhin, France.

setts. Fig. 53 and 54 show two Swiss roads. Fig. 55 shows a typical road in the Department of Bas-Rhin, France. The broken

stone is 6 inches deep. Fig. 56 is a typical French road in the Department of Seine-et-Oise.

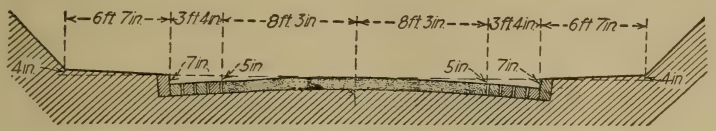

FIG. 56.—TPYICAL ROAD IN DEPARTMENT OF SEINE-ET-OISE, FRANCE.

366. PERMISSIBLE GRADES. For a general discussion of the subject of maximum and minimum grades, see § 79–86. The following examples of maximum grades for water-bound macadam roads are instructive.

In France the standard is: on national roads, not exceeding 3 per cent; departmental roads, not exceeding 4 per cent; and subordinate roads, not exceeding 6 per cent. On the great Alpine road over the Simplon Pass, built under the direction of Napoleon Bonaparte, the grades average 1 in 22 ($4\frac{1}{2}\%$) on the Italian side, and 1 in 17 (5.9%) on the Swiss side, and in only one case become as steep as 1 in 13 (7.7%).

In Great Britain, the celebrated Holyhead road, built by Telford through the very mountainous district of North Wales, has an ordinary maximum of 1 in 30 ($3\frac{1}{3}\%$), with one piece of 1 in 22 ($4\frac{1}{2}\%$) and a very short piece of 1 in 17 (5.9%), on both of which pieces special care was taken to make the surface harder and smoother than on the remainder of the road.

On the National Pike over the Alleghenies, built before the introduction of the railroad, the maximum was 7 per cent. At an early day the New York law limited the grades of turnpikes (toll roads) to 1 in 11 (9%).

In New York on state-aid roads the nominal maximum is 5 per cent, but grades as steep as $6\frac{1}{2}$ per cent have been found necessary in some cases. In New Jersey are a number of state-aid roads having grades of 7 and 8 per cent, and one has $10\frac{3}{4}$ per cent. In Massachusetts no hard-and-fast standard has been adopted for the state-aid roads, but a few have 5 per cent grades and a considerable number have 4 per cent grades. It is said that on some important Massachusetts roads the grade can not at reasonable expense be reduced below 7 per cent.

367. In improving city streets it is often impossible to make any radical change in the grade owing to the resulting damage to abut-

ting property, and it is almost impossible to avoid the steep grade by a change of location; and consequently some city streets have very steep grades which are used with surprisingly good results. Newton, Mass., has a number of water-bound macadam streets which have long stretches of 9 and 10 per cent grades, and has one 12 per cent grade 1,000 feet long. Waltham, Mass., has one 400-foot stretch of water-bound macadam on a 12 per cent grade, and another on a 13 per cent grade. In the Borough of Richmond (Staten Island), New York City, are several pieces of 10, 11, and 12 per cent grades, and 100 feet of 14 per cent, two stretches of 200 feet each of 16 per cent, and one piece 200 feet long of 20 per cent grade.

368. PREPARING THE SUBGRADE. The broken stone is designed to take the wear of hoofs and wheels, but the earth foundation must support the load; and therefore any road which is constructed without giving due attention to the earth road-bed is wrong from the start, and will never be a good road until the defect is remedied.

For instructions concerning the construction of embankments and excavations, see § 132–35. In building an embankment upon which broken stone is to be laid, every reasonable care should be taken to prevent uneven settlement. It is sometimes advisable to delay the laying of madacam for at least a year in order to give the embankment time to settle, for it is impossible to construct an embankment of earth more than a few feet in height without having subsequent settlement. If this settling took place evenly all along the embankment, no particular harm would be done to the macadam laid upon it; but owing to the difference in the soils composing embankments and also in the way the earth is dumped, there is always a tendency for some parts to settle more than others.

Sometimes the road surface is placed so low that it forms a gutter to drain the adjacent fields, which of course is very objectionable. Occasionally the earth from the side ditches and from the trench in which the stone is placed, is deposited at the side of the right-of-way instead of being used to raise the road surface. In this connection, see § 139.

369. After the subgrade has been brought to the proper form (§ 351), it should be rolled thoroughly—both to consolidate it and to discover soft spots. For a discussion of road rollers, see § 378–79.

Fig. 57 shows the method of smoothing the subgrade with a scraping grader; and also shows the rolling of the shoulder. Fig. 58 shows the subgrade after the rolling is completed.

In rolling, quicksand spots are sometimes discovered, in which

case the troublesome material should be excavated and suitable material substituted. If the road-bed be of sand or of material of such a nature as to push along in a wave in front of the roller, a thin layer of broken stone or gravel strewn over the surface will

FIG. 57.—SMOOTHING SUBGRADE AND ROLLING SHOULDER.

FIG. 58.—SUBGRADE ROLLED AND READY FOR STONE.

enable the roller to consolidate the road-bed. If the surface is clay that sticks to the roller, sprinkle a thin layer of sand or cinders over the surface. If the clay is soft and forms a wave in front of the roller, additional rolling is a detriment, as it increases the plasticity of the clay.

370. SETTING THE TELFORD. The distinguishing feature of a telford road is its paved foundation. After the road-bed has been brought to the proper form and been rolled, rough stones are set upon the surface to form a pavement 5 to 8 inches thick, the thickness depending upon that to be given to the finished road (§ 360), the general practice being to make the paved foundation about two thirds of the total thickness of the road. The practice of Telford

was to grade the road-bed flat, and then construct his pavement deeper in the middle than at the sides, using for a roadway 16 feet wide, stones about 8 inches deep at the middle and 5 inches at the sides. This practice is still followed by some engineers; but it is now more common and usually considered preferable to make the surface of the road-bed parallel to the finished surface, and the pavement of uniform thickness. Fig. 46, page 191, shows a telford road with a level subgrade; and Fig. 47, page 191, a telford road with the subgrade parallel to the finished surface.

The size of the stones for the telford pavement is of no great importance, at least there is a great difference in the practice of the best road builders. The width of the stones varies from 3 to 10 inches, 3 to 6 being most common; and the length varies from 6 to 20 inches, 8 to 12 being most common. It is desirable to have the width on any particular job somewhat nearly uniform, and the stones in any course should be still more nearly equal. The stones are set upon their widest edge with their greatest length across the road, the joints being broken as much as possible. Each stone should stand independently of its neighbor, i. e., one stone should not lean against another. The irregularities of the upper surface are then broken off with a hammer, and the interstices between the stones are filled with spalls lightly driven into place with a hammer or a crow-bar. This knocking off of the projecting points and the driving of spalls into the interstices should not be done so near the face of the pavement as to dislocate the stones last set. It is frequently specified that no wedging shall be done within 10 or 15 feet of the front edge of the pavement. After the projecting points have been knocked off and the interstices have been filled with stone chips or ordinary crushed stone, the pavement is usually rolled. It is usually specified that the roller shall not go nearer to the front of the pavement than 25 to 30 feet.

The cardinal requisite of a telford foundation is the interlocking of the stone closely and compactly together by barring, wedging, and rolling until the entire structure is brought in action to resist disturbance as a single mass.

371. CRUSHING THE STONE. The introduction of a machine for breaking the material greatly cheapened the cost of broken-stone roads. The rock crusher was introduced into America in 1860, before which time the stone was broken by hand with hammers on the side of the road. Coincident with the introduction of power for breaking the stone, came the revolving screen which

permitted the fragments to be assorted as to size—an important feature, as will soon be shown.

372. Forms of Crushers. There are two types of crushers now in common use. The older one, often called the Blake after the original inventor, consists of a strong iron frame, near one end of which is a movable jaw. By means of a toggle-joint and an eccentric, this jaw is moved backward and forward a slight distance. As the jaw recedes the opening increases and the stone descends; as the jaw again approaches the frame, the stone is crushed. The maximum size of the product is determined by the distance the jaw plates

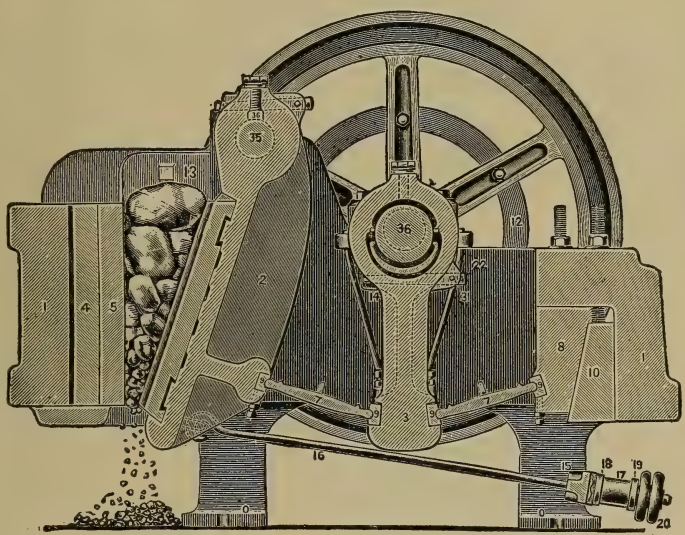

FIG. 59.—OSCILLATORY STONE CRUSHER.

are from each other at their lower edge. This machine is also frequently called the oscillatory breaker, or jaw breaker. Fig. 59 shows one form of this type. The size of the product is regulated by raising or lowering the wedge 10, or by inserting a different pair of toggles,—7.

The second form of crusher, called the Gates after the original inventor, consists of a solid conical iron shaft which is supported within a heavy iron receptacle shaped somewhat like an inverted bell. By means of an eccentric bearing a rocking and rotary motion is given to the shaft, so that each point of its surface is successively brought near to and removed from the surface of the bell, which causes the stone to be successively crushed as it descends. Fig. 60

shows one form of this type of crusher. An adjustment permits a variation in the size of the product. This form is often called the rotary breaker or gyratory breaker.

It is not wise here to consider the relative merits of the different forms and sizes of stone crushers, the power required, the output,

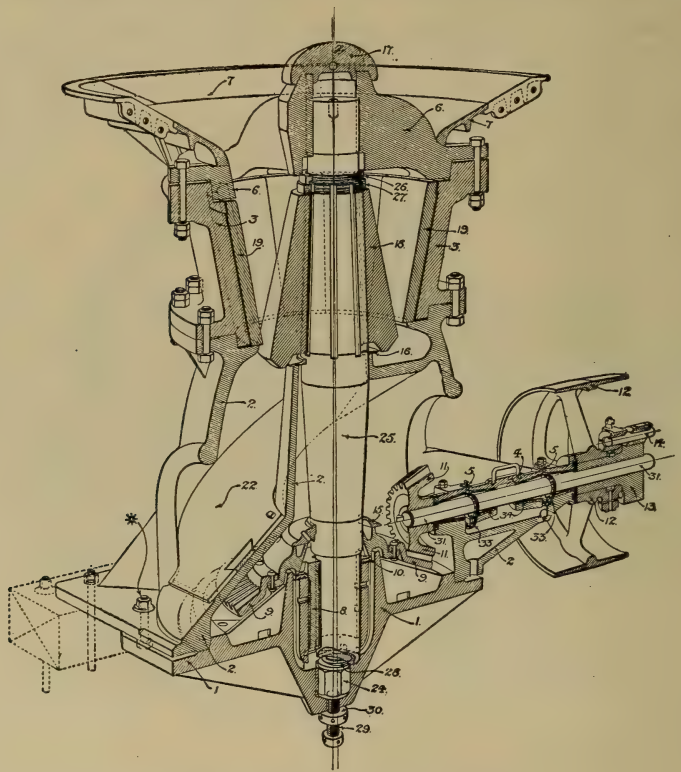

FIG. 60.—GYRATORY ROCK CRUSHER.

etc., since the construction of a reasonably good macadam road requires a large equipment of machinery and an experienced contractor, and since the equipment varies with the conditions.

Fig. 61 gives a hint as to the arrangement of the crusher, the elevator, the screens, and the storage bins. Fig. 62, shows a real crushing plant at Green Lake, Wis.

373. SIZES OF STONE. The size of stone used for road metal depends upon the hardness and toughness of the stone and upon the weight of the traffic. The harder and tougher the material, the smaller it may be broken without danger of its crushing or shat-

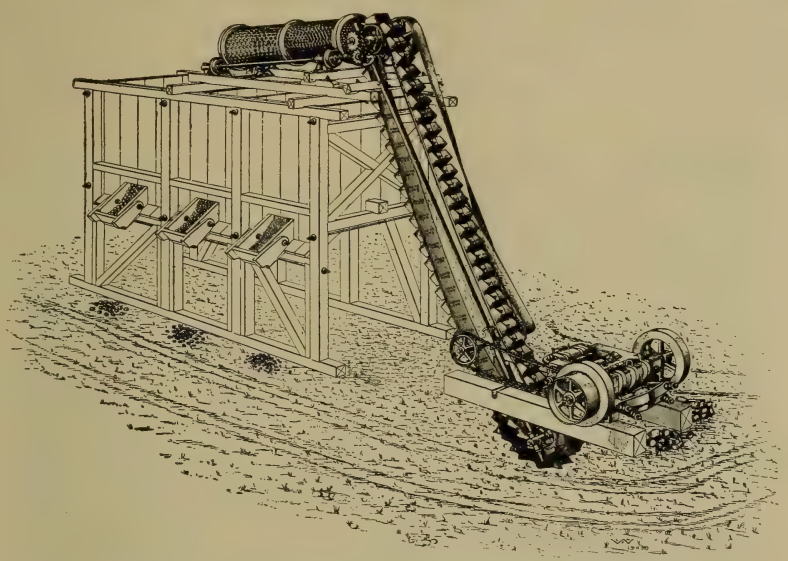

FIG. 61.—DIAGRAMMATIC ARRANGEMENT OF STONE-CRUSHING PLANT.

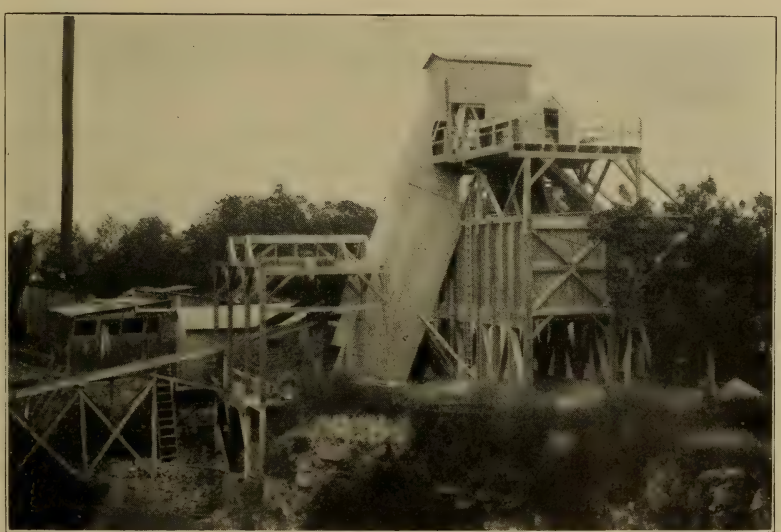

FIG. 62.—STONE-CRUSHING PLANT.

tering under the load of wheels and the impact of hoofs; and the harder and tougher a stone, the smaller it must be broken in order that it may compact well in the road. The stones in the top course should be larger for heavy traffic than for light traffic, to prevent their being ground to powder. Larger stones can be used in the bottom layers of a road than at the top.

One of MacAdam's rules was to exclude any fragment weighing more than 6 ounces. A $1\frac{1}{2}$-inch cube of compact limestone weighs about 6 ounces. Another of MacAdam's rules was to exclude any stone that could not readily be put into a man's mouth. These rules are frequently quoted, even now, although improvements in road machinery have made them inappropriate with present methods.

The bottom course of a macadam road built of soft stones is often composed of fragments 3 to 4 inches in greatest dimensions; but if it is built of hard tough stone, the sizes are 2 to $2\frac{1}{2}$ inches. The size of rock in the lower courses is not so important as that for the surface course (see § 374). The top course of hard tough stones is usually 1 to 2 inches for heavy traffic, and $\frac{1}{2}$ to 1 inch for light traffic.

The custom is to lay the stone in courses of substantially one size, although some road builders prefer to have the sizes mixed when thrown into the road. The only advantage of the latter practice is that with a skilful proportioning of the sizes less rolling is required; but it is objectionable owing to the difficulty of getting the several sizes properly proportioned and keeping them thoroughly mixed. There is generally too much fine material in the mixed sizes, which makes the road wear rapidly and unevenly.

Connected with the crusher and run with the same power is generally a rotary screen having meshes of three sizes—usually about $\frac{1}{2}$, $1\frac{1}{4}$, and $2\frac{1}{2}$ inches.

374. For economic reasons the size of stone in the several courses and their thickness should be adjusted so as to use, if possible, all of the output of the crusher. The output of the various sizes varies considerably with the character of the stone. With a hard stone, half or more of the product of the crusher will not pass through the $\frac{1}{2}$-inch screen; while with field stones one half may pass through such a screen. The last gives more "fines" or "screenings" than can be used profitably during construction, but the surplus is very useful in maintaining the surface. With some rocks it is difficult to get enough fine material for use in the original construction.

375. Spreading the Stone. The stone is usually hauled from the crusher to the road in wagons or trucks, dumped upon the roadway, and spread with forks or rakes. Dumping in place is objectionable, since the coarse and fine fragments become separated in

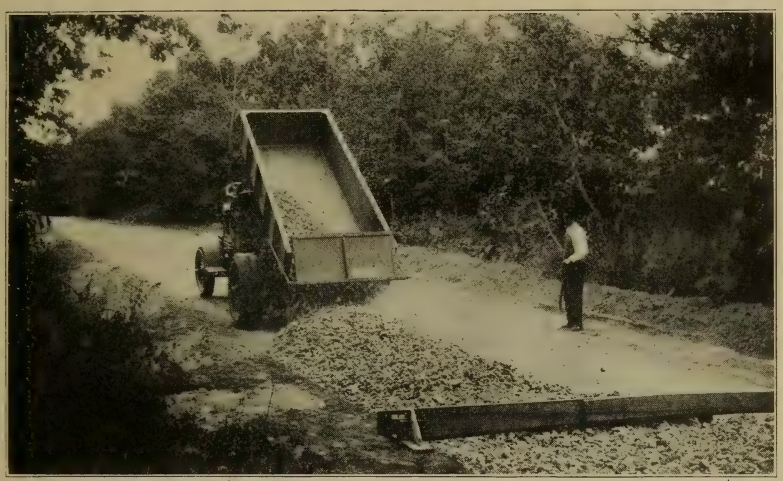

Fig. 63.—Auto Truck Dumping Stone.

the process, producing a layer of unequal density and an irregular surface after rolling. It is sometimes specified that the stone

Fig. 64.—Spreading Stone with Rakes.

Fig. 65.—Spreading Stone with Shovels.

shall be dumped upon a platform, from which it is distributed with shovels. This method of spreading costs 4 to 6 cents per cubic yard—about twice that by dumping and raking and is appropriate only when the very best results are sought. Wagons and

trucks are upon the market which can automatically dump and distribute the stone in layers of uniform thickness; but owing to their

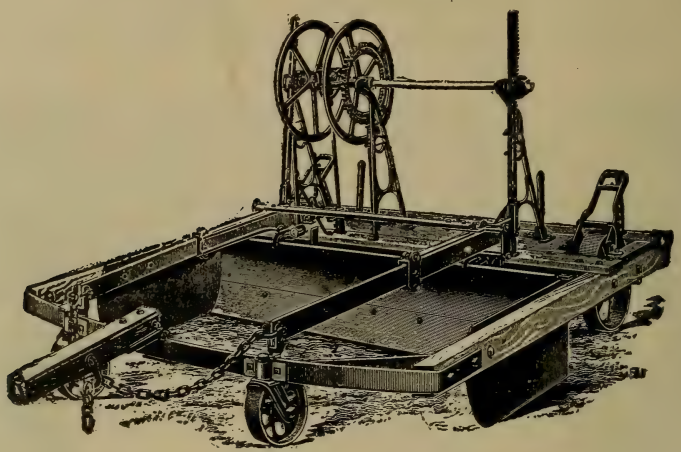

FIG. 66.—SHUART GRADER.

cost and weight they are not in very general use. Fig. 63 shows an auto truck dumping the stone in a ridge on the subgrade.

The stone is sometimes spread by hand with rakes and shovels—see Fig. 64 and 65. Notice the template in Fig. 65 used to gage the thickness of the layer of stone.

There are several methods of spreading the stone by machinery. Some contractors use the Shuart grader, Fig. 66, a machine that

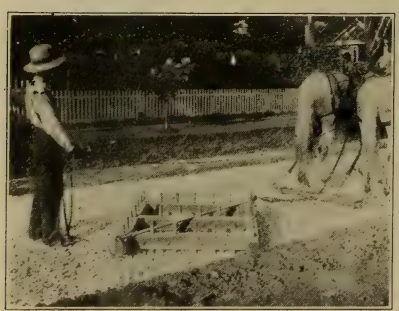

FIG. 67.—HARROWING STONE.

FIG 68.—LEVELING STONE WITH SCRAPING GRADER.

was devised for use in leveling ground that is to be irrigated. Other contractors level the stone with a harrow as shown in Fig. 67.

Still other contractors use a scraping grader to level the stone—Fig. 68. Fig. 69 shows the bottom course of stone ready for rolling.

The stone should be applied in uniform layers, the thickness of each depending upon the total thickness of the road. Two methods are in use for gaging the thickness of the layers of stone. 1. On the finished subgrade, wood cubes of a depth equal to the thickness of the layer are set at frequent intervals, and the loose

FIG. 69.—BOTTOM COURSE READY FOR ROLLING.

stone is laid even with the tops of these blocks. This method is sometimes described as building by blocks, and is the one employed on the state-aid roads of New Jersey. 2. The soil is brought to an established grade, and the finished road is required to be brought to another established grade, in which case neither the absolute thickness nor the uniformity of the several courses is a matter of much importance. This method is employed on the state-aid roads in Massachusetts.

376. SHRINKAGE IN ROLLING. Before beginning to spread the layers of stone, it is necessary to determine the amount the crushed stone will shrink in rolling. The shrinkage has an important bearing upon the thickness and cost of the finished road; but great errors are sometimes made in estimating the amount of shrinkage. The following examples from practice show the actual shrinkage.

In one case,* with trap rock $1\frac{1}{8}$ to $2\frac{1}{4}$ inches, rolled with a $12\frac{1}{2}$-ton steam roller upon a subgrade so hard that the wagons hauling the stone made no ruts, 5.67 inches of loose stone rolled to 4 inches, and 7.38 inches rolled to 6 inches. The average thickness of the loose stone was determined by dividing the quantity of stone used by the area covered. The first is a shrinkage of 29 per cent and the second of 19 per cent. The difference between these two results is probably due to errors of observation, to variations in the thickness of the finished road, and to the fact that the thicker layers did not compact as solidly as the thinner ones. The stone was rolled dry until the desired thickness was reached, when the binder was added, and sprinkling was commenced.

In another case,† with 2-inch trap laid on the compact surface of an old crushed-stone road and rolled with a 12-ton roller, 3.9 inches of loose stone rolled to 3 inches. The shrinkage was 23 per cent. The thickness was determined from the area covered and the quantity of stone used. No stone could have been forced into the subgrade, but there was some uncertainty as to the average elevation of the surface of the old street.

It has been determined ‡ by tests over several miles of road where the output of the crusher was carefully measured in wagons and also when rolled in place, that 6 inches of loose hard limestone rolled down to $4\frac{3}{4}$ inches, which is a shrinkage of 20 per cent.

377. It is probable that the maximum *actual* shrinkage in rolling is less than 20 per cent. The *apparent* shrinkage depends upon the nature and condition of the subgrade, i. e., upon the amount of stone forced into the earth.

If the soil is *clay*, the sprinkling required to work the binder into the interstices may soften the subgrade so that considerable stone will be forced into the earth. This condition is indicated by the roller's leaving tracks upon the surface; and when this occurs, the work should be stopped until the subgrade dries out. To prevent the crushed stone from being forced into the clay subgrade during construction or after completion—particularly when the frost is going out,—a layer of sand, stone screenings, ashes, or the like, is sometimes interposed. The English engineers often use "hard core" (a mixture of brick rubbish, old plastering, and broken stone) on a clay soil, to prevent the mud's working into the metaling. Any

* W. C. Foster in Trans. Amer. Soc. of Civil Eng'rs, Vol. 41, p. 135–38.
† F. G. Cudworth in Trans. Amer. Soc. of Civil Eng'rs, Vol. 41, p. 126–28.
‡ H. P. Gillette in Economics of Road Construction, p. 19–20. New York, 1901.

material not affected by water is useful for this purpose; and the finer it is the better, since the smaller will be the apertures in it, and the more certainly will it prevent the soil from coming up through it.

If the soil is *sandy*, a thin layer of coarse gravel or broken stone laid upon the surface and then rolled, will prevent any further loss of the road metal in the subgrade. If the soil is nearly pure sand, the wetter it is the less crushed stone will be forced into it; and therefore if water is plentiful, it may be wise to keep the sand saturated while the rolling is in progress to prevent the loss of the stone. The Massachusetts Highway Commission used cotton cheese-cloth on a soft fine sand to prevent the stone from sinking into the subgrade. "It is not at all needful that the partition should be enduring, for as soon as the stones in the lower layer have been forced into contact and have become bound together, there is no further danger of the mingling of the stone with the sand; and hence the decay of the fabric is a matter of no consequence. The cloth was spread in strips lengthwise of the way; and the stone for the bottom layer was shoveled from the sides upon it with no unusual care. A section through such a road showed that the stones did not tear through the cloth. At 3 cents per square yard on the road, the cost of the cloth may be less than one third that due to the loss of the broken stone which would occur if it were allowed to come directly in contact with the sand. Various kinds of strong paper were tried, but found worthless." A thick coating of straw has been used to hold up the macadam on a sandy soil.

However, if the sand is firm enough to hold up the stone during the rolling, it is not necessary to prevent the mixing of the sand and the stone, since the subgrade may be left a little high, with the expectation of forcing the stone into the sand. This is equivalent to using the sand of the subgrade as a filler or binder for the lower portion of the broken stone. If the sand is dry and nearly pure, it can be thus forced nearly to the top of a 4-inch course of coarse broken stone.

378. ROAD ROLLERS. The roller is indispensable for the economic construction of water-bound macadam roads. Roads can be built without the use of a roller, but always at large expense to the traffic and with great waste of the road metal; and such roads never have as smooth a surface and are not as durable as if a roller had been employed in their construction. With traffic-consolidated roads, much of the metal is worn round and smooth before the fragments become firmly fixed in place: and the dirt brought upon the road by

the traffic mixes with the stone and prevents it from ever packing as solidly as the clean stone would, and, besides, the dirt when wet has a lubricating effect upon the stone which under the action of traffic causes the surface to break up readily. Further, during the time travel is consolidating the stone, the surface is not even approximately water-tight; and therefore the subgrade is softened by rains, and the stone is mixed with the earth below and virtually lost.

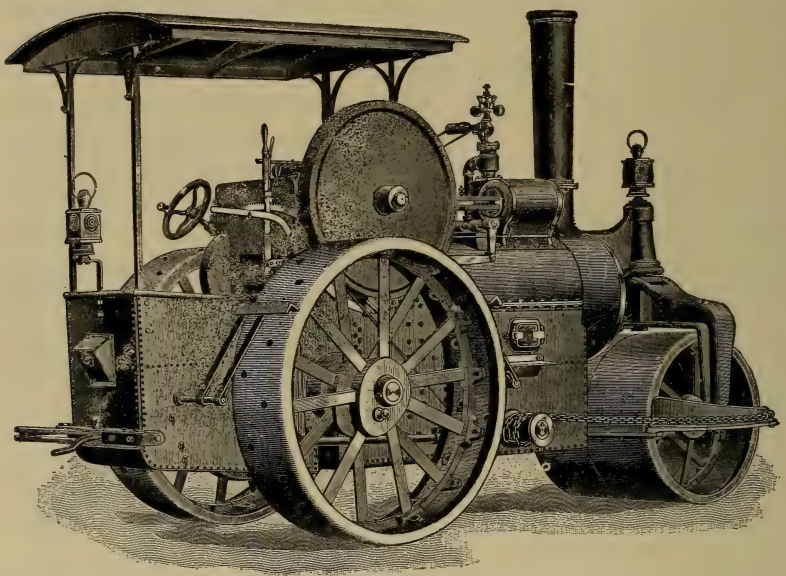

FIG. 70.—THREE-WHEEL OR MACADAM ROLLER.

Ordinarily, it is true economy to compact the road by the use of a roller.

Formerly both horse and steam rollers were employed; but now only the latter are used. There are two type forms of steam, or rather power, road-rollers—see Fig. 70 and 71. The first, or three-wheel type, is the form employed in macadam road construction; and the second, or tandem type, is the form used in rolling asphalt pavements and other bituminous road surfaces. Both types are driven by steam or by gasoline, but the latter is rapidly gaining in favor. There are a variety of forms of each type, but the essential features of all are practically the same.

The total weight of the macadam roller varies from 7 to 15 tons; and the pressure under the drivers varies from 300 to 500 lb. per linear inch. The total weight of the tandem roller varies from $2\frac{1}{2}$ to 10

tons, and the pressure under the driving drum from 125 to 300 lb. per linear inch and for the lightest roller the compression under the steering drum is usually about 60 lb. per linear inch. Of the tandem

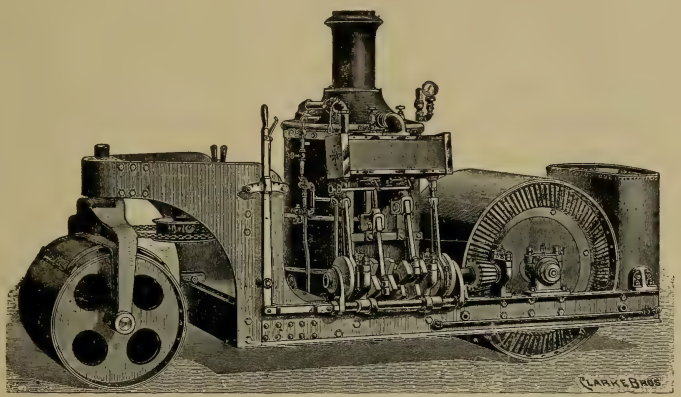

FIG. 71.—TANDEM OR ASPHALT ROLLER.

type the 5- and 8-ton roller are most common, and give a pressure under the driving drum of about 200 and 280 lb. per inch respectively.

379. The weight of the roller should be proportional to the hardness of the stone, as too heavy a roller crushes the material instead of compacting it. An excessively heavy roller will sometimes sink into light or loose soil, and force it ahead in a wave which the roller can not surmount. This may sometimes be prevented by spreading a thin layer of sand or gravel on the surface being rolled. A similar difficulty sometimes occurs with a heavy roller on a layer of loose stones. If the front wheels or rollers of the machine were larger, this difficulty would be decreased. In localities where the soil is of a loose sandy nature, a roller weighing 10 or 12 tons is usually preferred; and in districts where the soil is stiff or gravelly clay, a weight of 12 or 15 tons is used. In localities where the road material is hard, a 15-ton roller is necessary; but with the softer stones a weight of 10 or 12 tons is sufficient.

380. ROLLING THE STONE. Rolling is a very important part of the construction of a water-bound macadam road. The subgrade should be rolled to prevent the stones' being forced into the earth. The lower course of the stone should be rolled to compact it so that the pieces will not move one upon the other under the traffic and the top course should be rolled to pack or bind the pieces into place.

Rolling accompanied by sprinkling (see Fig. 72) is necessary also to work the binding material into the interstices so as to make the surface water-tight. Roads that have been consolidated by traffic are largely held together by mud, and after long use are fairly smooth and hard in dry weather, but become soft and muddy during a wet time.

The stone is put on in two or three layers,—according to the total thickness of the finished road,—and each course is thoroughly rolled

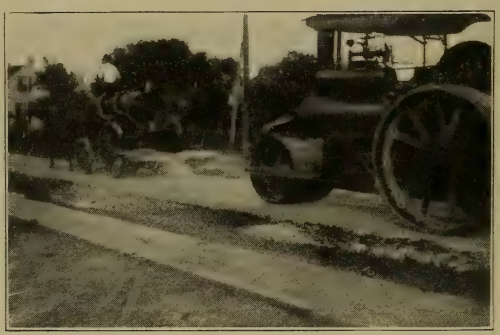

FIG. 72.—SPRINKLING AND ROLLING.

before the next is added. No course should be more than 4 to 6 inches thick. When a telford foundation is used, broken stone is spread over the pavement to bring the top surface to the proper form and height, after which it is rolled.

381. The rolling should proceed gradually from both sides toward the center. If the weight of the roller can be varied, commence with the unballasted roller, and increase the weight as the stone becomes consolidated. If the surface of the layer shows a wavy motion after being rolled three or four times, the subgrade is too wet; and time should be given it to dry out. Some coarse brittle granitic rocks begin to crawl and the sharp edges to break off after the roller has passed over them a few times; but a light sprinkling of sand or stone screenings will prevent this, and facilitate the consolidation of the layer. All irregularities of the surface developed by the rolling should be corrected by filling the depressions with stone of the size used in the layer.

The rolling should be continued until the stone ceases to creep in front of the roller, and until the macadam is firm under the foot as one walks over it. When the rolling is complete, one of the

larger stones of the course can be crushed under the roller without indenting the surface of the layer.

When the first course has been consolidated, a second, usually a thinner one of smaller stones, is added; and then it is rolled the same as the first. Finally a third course consisting of about half an inch of sand or fine stone and stone dust is added. The roller is then passed over this layer, with the result that the bits are ground to powder. As the rolling of this course proceeds it is sprinkled, the aim of the sprinkling and rolling being to work the fine material into the cavities between the pieces of crushed stone, thus binding the whole into a solid mass. The proper binding of the road is the most important part of the construction, and will be more fully considered presently (see § 383).

382. Amount of Rolling. The total amount of rolling required varies with the weight of the roller, the hardness and the size of the stone, and the amount of binder and water used. Trap rock being very hard requires two or three times as much rolling as most other stone. An excess of binding material and of water gives a compact surface with comparatively little rolling, but the road is not as durable as though it had been more thoroughly rolled.

The following examples are representative of the best American practice.

In New York City, 5 inches of crushed gneiss on telford and 5 inches of trap on the gneiss, bound with trap screenings, was rolled with a 15-ton steam roller at the rate of 40.6 square yards per hour, or 10 cubic yards per hour. Although it is common to give the amount of rolling in terms of the time required, the statement is somewhat indefinite, since the work accomplished varies with the speed of the roller and also with the length of run, i. e., with the time lost in starting and stopping. The usual speed of steam rollers is 2 to $2\frac{1}{2}$ miles per hour. The above work is equivalent to 0.553 ton-miles per square yard, or 2.246 ton-miles per cubic yard. The number of trips was 130.*

In making repairs, a 6-inch course of 2-inch trap was rolled at the rate of 26.2 square yards per hour, or 4.4 cubic yards per hour. The work amounted to about 0.859 ton-miles per square yard, or 5.177 ton-miles per cubic yard. The number of trips over the surface was 201.†

An area of 22,000 square yards or a 3-inch course of 2-inch trap

* Trans. Amer Soc. of Civil Engineers, Vol. 8, p. 105–6.
† *Ibid.*, p. 107.

upon an old broken-stone road, bound with trap-rock screenings and rolled with a 10-ton steam roller, was finished at an average rate of 47.15 square yards per hour of rolling, the extremes being 38.4 and 61.1 square yards per hour. This was an average of about 4.0 cubic yards per hour.*

A 6-inch course of $1\frac{1}{8}$- to $2\frac{1}{4}$-inch trap rock, bound with limestone screenings, was rolled with a $12\frac{1}{2}$-ton steam roller at an average rate of 31.4 square yards per hour, or 5.2 cubic yards per hour.†

The Hudson County Boulevard (Jersey City, N. J.) consists of 8 inches of telford, $2\frac{1}{2}$ inches of $2\frac{1}{2}$-inch stone, $1\frac{1}{2}$ inches of $1\frac{1}{2}$-inch stone, and then $\frac{1}{2}$ to 1 inch of coarse screenings—all trap rock. The macadam top was supposed to roll down to 4 inches, i. e., $4\frac{1}{2}$ to 5 inches of loose stone was supposed to roll to 4 inches. The rolling was distributed about as follows: On the telford, 10 to 12 passages; on the $2\frac{1}{2}$-inch course, 8 to 10 passages; on the $1\frac{1}{2}$-inch course, 10 to 12; and on the screenings, 80 to 90,—making a total of 100 to 120 passages of the roller over the road.

383. BINDING THE ROAD. The interstices between the fragments of stone should be filled with a fine material which will act mechanically to keep out the rain water and thereby keep the subgrade dry, and also to support the fragments and prevent them from being broken, and which will bind or cement the fragments into a single more or less solid mass. The proper binding of the stone is the most important part of the construction of a water-bound macadam road.

384. Nature of the Binder. The binding material or the filler should be finely divided so as to be easily worked into the interstices, should have a considerable resistance to crushing so as to properly support the pieces of crushed stone, and should not change its physical condition when wet. Various materials have been employed —clay, loam, shale, sand, and limestone and trap-rock screenings.

Clay and loam are frequently used. Their merit is that they are cheap, are easily applied and have a high cementing power; but they are easily affected by water and frost, and when wet act more as a lubricant than as a binder. Clay or loam binder will give a smooth road without much rolling, but such a road is liable to be very dusty in dry weather, and muddy in wet weather. When clay or loam is employed as a binder, the utmost care should be taken that no more is used than just enough to fill the voids.

*Trans. Amer. Soc. of Civil Engineers, Vol. 41, p. 127.
†*Ibid.*, p. 138.

Shale and slate are only hard and compact clay, and their only merit is that they give a smooth surface with but little rolling. They are speedily reduced to dust, and then have all the disadvantages of clay. They have only fair cementing power.

Sand is often used as a filler, and if composed of fine, clean, hard grains, gives fair results; but sand which is resistant enough for a good binding material usually consists of silica or quartz, neither of which has a high cementing power. If the grains are coated more or less with iron oxide, or if accompanied by bits of ironstone (clay cemented with iron oxide), sand makes an excellent binding material, since the iron possesses considerable cementing power. This form of binder is particularly valuable in making repairs over an opening when a roller is not available, or when water for washing in the binder is scarce. Low-grade iron ore has been used for a binder—either alone or mixed with stone dust.

Fine screenings—the finest product of the stone crusher, say, from $\frac{1}{2}$ or $\frac{1}{4}$ inch to dust—from the stone used in the body of the course is the most desirable material for a binder, partly because it helps to utilize the entire product of the crusher, partly because of its high crushing strength, and partly because the stone is usually selected for the high cementing power of its dust. Limestone has very high cementing power, but is soft and pliable. Trap has a fair cementing power, and is hard and durable. Limestone screenings require less rolling, but the trap dust makes a more durable road.

Sometimes the detritus removed from the surface of a stone road during maintenance or preparatory to making repairs, is employed as a binder. At best, such material is very poor for this purpose. It is worn out and has performed its duty; and, besides, it is composed largely of manure and vegetable and earthy matter—all of which are very undesirable in a binder. Such detritus is more valuable as a fertilizer than as a road material.

385. Applying the Binder. There is a difference of opinion among competent engineers as to the best method of applying the binding material. Some apply it on the top of each course, and some on top of only the last course. In the first case, all the voids from the bottom to the top of the road are filled with fine material; in the second case, the binder usually fills the voids of the top course only. Those who advocate the first method claim that the whole mass should be filled to prevent the stones from moving under the traffic, and also to prevent the soil from working up from below; while the advocates of the second method claim (1) that filling the

top layer is sufficient to hold the stone in place near the surface, (2) that the stones of the lower courses have no tendency to move, (3) that the unfilled voids of the lower course promote drainage, and (4) that as the upper layer wears away, the dust will wash down into the lower open spaces in such a manner as always to keep the 3 or 4 inches just below the surface properly bound. If the stone is hard, or if the lower courses are not thoroughly rolled, applying the binding material only on the top of the last course practically fills the voids to the earth foundation; but of course it is cheaper to apply the filler on the top of each course than to attempt to fill all of the voids by applying it on the top course only. If the stone in the lower courses is soft, or if the top of the next to the last course is thoroughly rolled, applying the binder on the top fills the voids in the top course only. It is sufficient to fill the voids of the top course.

The binder is applied by spreading a layer of " fines " about half an inch thick over the partially rolled surface. The filler should be dumped upon a board platform, and not directly upon the road surface; and should be distributed evenly over the stone with a shovel. Under no consideration should loam or vegetable matter be allowed to contaminate the stone screenings. After the binding material has been evenly distributed, the surface is then sprinkled and rolled. The sprinkler should have many fine openings, the object being to give a gentle shower rather than a violent flooding. The water washes the fine material into the cavities below, and the roller crushes the small fragments and makes more dust. The rolling also aids in working the binder into the mass; in fact, the binder can be worked in to a considerable extent by dry rolling, and consequently the quantity of water used varies widely with the method of doing the work, but is usually about 4 to 6 cubic feet per cubic yard of stone. Sometimes men with heavy brooms are kept upon the road sweeping the binding material about to assist in working it in, and also to secure a more uniform distribution of it. While applying the screenings care should be taken to pick off any coarse stone—particularly flat ones,—as they do not bind well and their subsequent loosening causes the road to ravel (§ 397).

As the rolling and sprinkling proceed, fine material should be added where needed, i. e., as open spaces appear. All the filler should not be put on in the beginning, since a thin layer can be worked in to better advantage than a thick one; and, besides, it is desirable to use only enough to fill the voids.

Occasionally the surface of the road becomes muddy and sticks

to the roller. This can be remedied in either of two ways: viz., by sprinkling the roller and keeping it constantly wet, or by keeping the sprinkling wagon immediately in front of the roller and having the binder always fully saturated. The rolling is continued until the water is forced as a wave in front of the roller and until the surface behind the roller is mottled or puddled and is covered with a thin paste. The binding, or the puddling of the surface, can not be done satisfactorily when the surface freezes nightly.

When finished, if the road is allowed to dry and is then swept clean, the surface will be seen to have the appearance of a rude mosaic, the flat faces of the fragments of stone being crowded against one another and the interspaces being filled with the binding material —the latter occupying about half of the area. Such a surface when dry will stand considerable sweeping with a steel broom or brush without the fragments of stone being loosened. The water used in construction not only aids in working the binder into the interstices, but also develops the cementing power of the rock dust.

386. Usually after the rolling has been completed a thin coating of binding material is sprinkled over the surface. Authorities differ as to the amount of fine material to be left on the finished surface, some specifying as little as $\frac{1}{8}$ inch and some as much as 1 inch, the usual quantity being $\frac{3}{8}$ to $\frac{1}{2}$ inch. If only enough binding material to fill the interstices between the coarser fragments is left upon the road, the fine material will be blown and washed away, and soon there will not be enough to level up between the large bits and to hold the surface stones in place, when the wear will come directly upon the stones. On the other hand, if any considerable quantity of fine material is left upon the surface, it is speedily ground up, and becomes offensive dust if it is not sprinkled, and equally objectionable mud if it is sprinkled. It is probably best to put on a quantity just sufficient to give a thin layer, say, $\frac{1}{4}$ to $\frac{3}{8}$ inch, over the surface, and when this amount is blown or washed away renew it. By this method, the wear on the body of the road will be prevented, a minimum amount of sprinkling will be required, and there will be as little dust as possible. The surface coat is also serviceable in decreasing the tendency of the binding material to dry out and to lose part at least of its cementing power. Fine material over and above that required to fill the interstices is useful only to prevent raveling and to keep the wear from the surface of the stone; and therefore sand is as good for the top dressing as stone dust, and is usually much cheaper. It is desirable that this

coat of fine material shall be sprinkled and rolled before the traffic is admitted.

The road is now finished; and after it has dried out for a day or two, it may be thrown open to traffic.

387. Amount of Binder. The amount of binder required depends upon the hardness of the stone and the amount of rolling preceding the application of the binder (§ 385). The voids in the broken stone can be reduced by rolling to 20 or 25 per cent, say 22 per cent, of the compacted mass; and the completed road will contain 4 to 7 per cent, say 5 per cent, of voids; and therefore enough binder must be added to fill about 17 (= 22 − 5) per cent of voids. The binder itself usually contains 40 to 50 per cent of voids, and therefore the volume of filler required is 40 to 50 per cent more than the voids to be filled, i. e., 40 to 50 per cent more than 17 per cent of the original volume of stone; or, in other words, the amount of filler required is 25 to 35 per cent of the thickness filled. This allows a little for waste and for the thin coating spread upon the finished surface. If the binder is applied before the rolling has progressed very far, more fine material will be required, since some of it will work in between the fragments of stone and prevent them from coming into as close contact as they otherwise would. In this case, part of the surplus binder will be flushed to the surface during the sprinkling and rolling, as mortar flushes to the surface in tamping concrete; but in no case does all the surplus thus work out, and consequently the road is not as durable as though only enough binder had been used to fill the voids; and, further, the binder which flushes to the surface must be removed as mud. An excess of binder is often used to reduce the cost of construction by decreasing the amount of sprinkling and rolling required; but such a practice adds to the cost of maintenance, and the road is less durable and more dirty.

388. Cost of Construction. The cost of construction of a crushed-stone road varies greatly with the size of the job, the conditions of the material and labor markets, the specifications under which the work is done, etc. It is unwise to give here any details as to the cost of the several parts of the work; and only a few data will be given concerning the total cost of a road. The total cost varies with the amount of grading and drainage required, the length improved in a single season, the length of railroad and wagon haul, the specifications, the labor market, etc. The following are a few representative examples of first-class construction.

The values here given are somewhat out of date; but present

values are quite abnormal owing to the Great European War. The data given below are interesting chiefly as showing relative cost in different localities and of the different parts of the work. For current prices consult the construction news in technical journals.

389. *New Jersey.* In northern New Jersey, the total cost of trap macadam roads 4 to 6 inches deep, where the rock was obtained near the road, ranged from 20 to 45 cents per square yard; and telford roads consisting of 8 inches of telford and two courses of broken stone $2\frac{1}{2}$ and $1\frac{1}{2}$ inches thick respectively, cost from $1.02 to $1.29 per square yard. In the southern part of that state, where the stone is transported 20 to 70 miles, 8-inch trap macadam roads cost from 23 to 70 cents per square yard, the average being from 50 to 60 cents per square yard.*

390. *Massachusetts.* The average cost of 220 miles of state-aid roads in Massachusetts built from 1894 to 1899,† reduced to the

TABLE 27

COST OF MASSACHUSETTS STATE-AID WATER-BOUND MACADAM ROADS

Items of Expense.	Per Cent of Total Cost.
Earthwork at 32.1 cents per cubic yard	16.4
Rock excavation at $1.80 per cubic yard	2.0
Shaping earth subgrade at 2.0 cents per cubic yard	2.4
Gravel for foundation and wings at 55.8 cents per cubic yard	3.5
Telford foundation at 33.9 cents per square yard	0.2
Broken stone at { $1.503 per ton for local stone / $1.920 per ton for trap }	45.3
Side drains at 34.5 cents per lineal foot	2.7
Rubble masonry—dry, at $3.133 per cubic yard	2.6
" " in cement, at $5.770 per cubic yard	3.3
Guard rails at 16 cents per lineal foot	1.7
Stone boundary-posts at $1.417 each	0.6
Paved cobble gutters 66.0 cents per square yard	1.1
Vitrified-clay pipe-culverts—12-inch, at 65 cents per lineal foot	1.2
Land damages, catch basins, and minor items of construction	3.0
Engineering and inspection	14.0
Total	100.0

equivalent cost of a " standard mile " (15 feet wide), was $9,931.23 per mile for construction and engineering expenses, exclusive of cost of administration and the salaries of the chief engineer and two

* Compiled from the Reports of the State Commission of Highways of New Jersey, 1895-1900.

† Report of Massachusetts Highway Commission, 1900, p. 150–57.

assistants. The maximum average for the roads in any township was $20,257.48 and the minimum $4,871.30 per "standard mile." The above gives an average cost of $1.126 per square yard, a maximum of $2.302, and a minimum of $0.564.

In Massachusetts in 1897, 52 miles were built in 187 towns (townships), the average cost of the several items being as shown in Table 27.* An examination of the reports for other years indicates that the above exhibit is fairly representative, except that the expenditure for stone is smaller than the average. In the state-aid roads built from 1894 to 1899, the cost of the broken stone was equal to 55 per cent of the total cost of the road, but in later years the amount of stone used was decreased.

391. *New York.* In the State of New York in 1898, 22 miles of state-aid macadam roads were built in six sections, with an average cost of 84.0 cents per square yard, the maximum being $1.085 and the minimum 64.8 cents. The roads consisted of 4 inches of native stone, and 2 inches of trap rock bound with limestone screenings.†

392. *Michigan.* In Michigan the average cost of 52 miles of water-bound macadam roads is as follows: ‡

Items.	Average.	
	Per Mile.	Per Sq. Yd.
Broken stone, cubic yards	1 653	0.313
Grading, shaping and draining	$ 435.85	$0.083
Crushed stone	2 264.88	0.523
Culverts	71.80	0.013
Surfacing, including loading and hauling	1 621.91	0.307
Total	$4 394.44	$0.925

393. *Missouri.* In Missouri the average cost of two-course work is as stated in the table at the top of page 223.§

394. SPECIFICATIONS. The American Society of Municipal Improvements publish specifications for water-bound broken-stone roads, printed copies of which may be had for a nominal sum. These specifications are changed from time to time as is necessary to keep them up to date.

* Report of Massachusetts Highway Commission., 1898, Appendix C, p. 74–75.
† Report of New York State Engineer and Surveyor, 1899, p. 37.
‡ *Engineering and Contracting*, Vol. 41 (1914), p. 705.
§ *Ibid.*, Vol. 38 (1912), p. 14.

Items.	Per Sq. Yd. of Road Surface.	Per Cu. Yd. of Loose Stone.
Quarry rent	$0.013	$0.05
Quarrying	0.100	0.40
Crushing	0.075	0.30
Hauling, 1 mile	0.075	0.30
Shaping road-bed	0.025	0.10
Spreading material	0.025	0.10
Rolling	0.013	0.05
Sprinkling	0.013	0.05
Superintendence	0.013	0.05
Incidentals	0.013	0.05
Total, exclusive of interest and depreciation on plant, profits, and administration	$0.364	$1.45

ART. 3. MAINTENANCE

395. After the road has been properly rolled and the surface has been made compact and smooth, it is very desirable that it should always be maintained in that condition. Many seem to believe that a macadam road is a permanent construction which needs no attention after completion; but proper maintenance is as important as good construction.

Formerly much attention and study was given to the causes of wear of water-bound macadam roads; and it was needed, for many such roads were subjected to a heavy travel, and required great care to keep them in usable condition. To maintain the roads in good condition it was necessary to make repairs either at frequent intervals or continuously, and to add new material as the old was washed off or blown away. But the coming of the automobile made necessary a radical change in the methods of maintenance and construction of broken-stone roads. With horse-drawn vehicles the abrasion of the horses' feet and of the metal tires wore off dust or binder to replace that washed off and blown away; but the fast-moving low-hung body of the automobile threw more of the road dust into the air than horse-drawn vehicles, and hence more of the binder was blown away, and besides the automobile made no dust to replace that blown away. Further, the action of the wheels of the automobile, particularly in starting and stopping and in rounding curves, tends to dislodge the stones.

Therefore the introduction of the motor-driven vehicles radically changed the method of maintenance of the broken-stone roads. Instead of trying to maintain a water-bound macadam road having

any considerable amount of motor-driven traffic, by adding new material to replace that washed off and blown away, it became the practice to give the surface of such roads a coating of bituminous material, such as tar or asphalt, which prevented the formation of dust and also protected the surface from wear. This method of treatment is discussed in Chapter IX.

396. Since the introduction of motor-driven vehicles, the only water-bound macadam roads not protected by a bituminous coating are those that carry only a small amount of travel, particularly a small number of motor vehicles; and hence the maintenance of such roads is not of great importance. Therefore the maintenance will be considered only briefly.

397. RAVELING. One of the chief evils to be contended with in the maintenance of a crushed-stone road is the tendency to ravel, i. e., for one stone after another to work loose on the surface. This occurs only after a long dry spell or in a road originally deficient in binding power, and is more likely to occur on lightly traveled roads than on those having heavy traffic. Raveling may take place where the wind sweeps away the binding material from the surface, or on a steep grade where the water has washed the fine material away from between the fragments; and is chiefly due to the picking of the horses' shoes, which in a measure is counteracted by the rolling action of the wheels.

Two expedients are employed to prevent raveling. 1. Sprinkling the road with water effectually stops raveling, and causes the surface to solidify again. This is the most common remedy on city streets and suburban roads—where water is usually convenient and plentiful. For a further discussion of Sprinkling, see § 401. 2. A thin coating of coarse sand is very effective in preventing raveling. Ordinarily on country roads a layer half an inch thick is sufficient. Unless the season is very dry or the road is unusually exposed to the wind, a single application will be enough for one season.

398. RUTS. Next after raveling, the tendency to form ruts is the most serious evil to be contended against in the maintenance of crushed-stone roads. Ruts are due either (1) to a greater wheel load than the road is capable of standing, or (2) to the use of an inferior binding material, as loam, or (3) to tracking. Ruts are most likely to occur in the spring or during a wet time, when the roadbed is soft, and are more common on country roads than on city streets, since in the latter the frequent changes in direction to avoid other vehicles produce a more uniform wear over the whole surface of

the road. However, a street-car track in a broken-stone road prevents the distribution of traffic uniformly over the entire surface and greatly increases the tendency to form ruts.

After ruts appear the only remedy is to fill them either with new material or by picking down the sides of the ruts and raking the loosened material into the depression. Usually the latter course is the wiser, particularly on a new road. Frequently the tendency to form a rut may be effectually arrested by sweeping into it the loose detritus from the adjacent parts of the road. If the road surface is compact and hard, it may be necessary to loosen the bottom and sides of the rut before adding new material, so that the new will thoroughly unite with the old. The new material should be of the same character as the old, as otherwise the surface will wear unequally and become rough.

399. PATCHING. Formerly much attention was given to the patching of macadam roads to keep the surface free from ruts and depressions (see pages 253–57 of the former editions of this treatise); but the only water-bound macadam surfaces now in use are those having a comparatively small amount of travel, and therefore the repair of such roads is a comparatively simple matter.

When new stone is added, the old surface should be loosened to insure that the new stone will unite with the old. The patch should be rounded rather than square cornered. Care should be taken to leave no place where water may lodge. When new, the patch should be a little higher than the adjoining surface. The stone employed in patching should be a little smaller than that used in the original construction. It is better to lay the stone in two thin courses than in a single thick one, and allow the first to become consolidated before the second is added. Ordinarily, in applying patches in thin coats over small areas it is unnecessary to use binding material, since the road usually has enough detritus to fill the interstices of the new stone. If laid in damp weather, when the surface of the road is soft, there is usually no difficulty in getting a layer one-stone thick to consolidate without any binding material. If the patch is small and thin, it will usually not be necessary to tamp or roll it.

When the surface of the road has become uneven and rough, and when the broken stone is thick enough not to require much new material, the top of the road is loosened, re-graded, and re-rolled. The loosening is usually done by running over the road, one or more times, with a steam stone-road roller having spikes in the rear wheels, or by breaking up the surface with a scarafier,—a cross between a plow

and a harrow. After the crust is broken up, the surface is leveled off by the use of a harrow and hand shovels and rakes; and then it is sprinkled and rolled as in the original construction. Usually no new binding material is required, the detritus from the old road being sufficient.

400. ROLLING. In the spring after the frost goes out, the road bed is soft and porous; and a thorough rolling with a steam roller at this time, before the subgrade is dry, is one of the best and cheapest methods of keeping a macadam road in good condition. Just before this rolling is the time to add a little fresh surface material, here and there, as may be needed to fill up slight depressions.

401. SPRINKLING. Moisture is necessary to preserve the cementing power of the binding material, and also to prevent an excessive removal of dust by the wind; and therefore sprinkling to the extent required to prevent these injuries is an advantage. The water should be applied in a fine spray, and not be allowed to run in streams on the road; that is, several light sprinklings are better than a single flooding. If sprinkled too heavily or too often, the road is softened and breaks up easily.

Sprinkling is usually employed on park drives and city streets, where it is generally conceded to be true economy, without taking into consideration the prevention of dust; but it never was much used on rural roads on account of the expense, and the introduction of bituminous coatings as dust preventatives has entirely done away with sprinkling as a road preservative.

402. For a discussion of sprinkling with water, oil, etc., see § 325–31 under Gravel Roads.

For a discussion of bituminous coatings for macadam roads, see Art. 1 and 2 of Chapter IX.

403. COST OF MAINTENANCE. The introduction of automobiles greatly increased the cost of maintaining water-bound macadam roads (see § 395). Data on the cost of maintaining water-bound roads before the advent of motor-driven vehicles are now of little or no value; and there are almost no data on the cost of maintenance of such roads where the amount and character of the travel is known.

CHAPTER VII

PORTLAND-CEMENT CONCRETE ROADS

406. Definitions. The wearing coat of a concrete road is a layer of portland-cement concrete. The word concrete ordinarily means a mass of pebbles or broken stone bound together into a solid mass by hydraulic cement; and the word cement in engineering literature ordinarily means hydraulic cement, and in recent years it usually means portland cement. Until recently the type of road considered in this chapter was called a concrete road. However, the preceding meanings do not now apply in discussions concerning roads and pavements. Recently a form of construction has been introduced in which the pebbles or fragments of broken stone are held together by bituminous cement instead of hydraulic cement; and therefore to prevent the possibility of misunderstanding it is wise to employ the terms portland-cement concrete road or simply portland-concrete road, and bituminous-cement concrete road or simply bituminous-concrete road, to designate these two types.

407. History. Except three comparatively small sections constructed earlier, concrete was not used for road surfaces until the early years of this century. In 1909 there were in this country less than a half million square yards; but in 1916 there were laid in this country 24 million square yards of such road surfaces, an increase of forty-eight times in 7 years. At present about 50 per cent of such surfaces are on rural roads, and about 25 per cent each on streets and alleys.

Art. 1. The Materials

408. The concrete is composed of portland cement, sand or stone screenings, and pebbles or broken stone. The sand or stone screenings are often called the fine aggregate, and the pebbles or the crushed stone the coarse aggregate.

409. Cement. For a discussion of the characteristics of the

different types of hydraulic cement and of the methods of testing the same, see pages 54–83 of the tenth edition of the author's Treatise on Masonry Construction.* The only form of hydraulic cement used in concrete roads is portland cement.

It is almost universally specified that the cement shall meet the requirements of the latest standard specifications of the American Society for Testing Materials, which also have been adopted by all of the national engineering associations. Printed copies of these specifications can be had of the above Society for a nominal sum; and they have been republished by various organizations.

410. FINE AGGREGATE. For an extended discussion of the characteristics and requirements of sand and screenings for making concrete and the method of testing each, and also for a discussion of the relative merits of sand and screenings, see pages 85–97 of the tenth edition of the author's Treatise on Masonry Construction.*

411. Sand vs. Screenings. The finer particles screened out of the broken stone are sometimes used in concrete instead of sand; and there is much discussion as to the relative merits of sand and screenings. Experiments show that if all conditions are the same, the screenings make slightly stronger mortar; but in practice it has been found nearly impossible to exclude dust from the stone screenings, particularly if the stone is soft (as is most limestones) or if the screenings get wet before being screened, and hence in practice mortar or concrete made from screenings is not usually as strong as that made of sand of the same degree of fineness. For these reasons many engineers prohibit the use of stone screenings.

412. The specifications for the fine aggregate recommended by the 1916 National Conference on Concrete Road Building are as follows:

"The fine aggregate shall be natural sand or screenings from hard, tough, durable crushed rock or gravel; and shall consist of quartzite grains or other equally hard material graded from fine to coarse with the coarse particles predominating. When dry it shall pass a screen having four meshes per linear inch, and not more than 25 per cent shall pass a sieve having fifty meshes per linear inch, and not more than 5 per cent shall pass a sieve having one hundred meshes per linear inch. It shall not contain vegetable or other deleterious matter, nor more than 3 per cent by weight of clay or loam. Routine field tests shall be made on the fine aggregate as delivered. If there is more than 5 per cent of

* A Treatise on Masonry Construction, by Ira O. Baker. 745 pages, 6 × 9 inches. John Wiley & Sons, New York City. Tenth Edition, 1909.

clay or loam by volume settled after one hour's shaking in an excess of water, the material represented by the sample shall be held pending laboratory tests.

"The fine aggregate shall be of such quality that mortar composed of one part portland cement and three parts fine aggregate, by weight, when made into briquettes, shall show a tensile strength (at seven and twenty-eight days) equal to or greater than the strength of briquettes composed of one part by weight of the same cement and three parts standard Ottawa sand. The percentage of water used in making the briquettes of cement and fine aggregate shall be such as to produce a mortar of the same consistency as that of the Ottawa sand briquettes of standard consistency."

413. COARSE AGGREGATE. For a discussion of the requisites of gravel and broken stone for concrete, see pages 97–103 of the tenth edition of the author's Treatise on Masonry Construction.

414. Gravel vs. Broken Stone. There is difference of opinion as to the relative merits of gravel and broken stone for concrete. The elements to be considered are the strength, density, and cost of the concrete.

Gravel concrete has only about 80 to 90 per cent of the strength of broken-stone concrete.

Experience shows that gravel concrete is more easily compacted, and has fewer cavities than broken-stone concrete; and hence gravel concrete is denser and more waterproof.

As a rule, the first cost of gravel is less than that of broken stone, and the former is considerably easier to handle.

415. However, since gravel is liable to contain so much clay or loam as to materially reduce the strength of the concrete, some engineers for this reason alone prefer broken stone to gravel. Even though only portions of the gravel are naturally dirty, or even though only portions of it are likely to contain an undue amount of the stripping, some engineers, owing to the greater care required in inspection and to the uncertainty of eliminating all dirty gravel, prefer broken stone to gravel.

416. The Specifications for the coarse aggregate recommended by the 1916 National Conference on Concrete Road Building are as follows:

"The coarse aggregate shall consist of clean, hard, tough, durable crushed rock or pebbles graded in size, free from vegetable or other deleterious matter; and shall contain no soft, flat or elongated particles. The size of the coarse aggregate shall be such as to pass a 1½-inch round opening, and shall range from 1½ inches down; and not more than 5 per cent shall pass a screen having four meshes per linear inch, and no intermediate sizes shall be removed.

"Crusher-run stone, bank-run gravel, or artificially prepared mixtures of fine and coarse aggregate shall not be used."

417. Theory of Proportions. The whole theory of the proper proportions for concrete is comprised in two laws as follows:

1. For the same fine aggregate and the same coarse material, the strongest concrete is that containing the greatest per cent of cement in a unit of volume.

2. For the same per cent of cement and the same aggregates, the strongest concrete is made with that combination of fine and coarse aggregate which gives a concrete of the greatest density.

The first law is almost self-evident, and concerns the relative richness of the concrete. Experiments have shown this law to be almost mathematically exact.

The second law is very important, and concerns the qualities of the fine and coarse aggregates. The second law is equivalent to saying that the cement should fill the voids of the sand, and that the resulting mortar should fill the voids of the coarse aggregate. If the cement does not fill the voids of the sand, or if the mortar does not fill the voids of the coarse aggregate, the concrete will obviously be less dense than though the voids were just filled. If the paste is more than enough to fill the voids in the sand, or if the mortar is more than enough to fill the voids in the coarse aggregate, the concrete will be less dense than though the voids were just filled; since both the paste and the cement mortar have a less density than ordinary concrete; and hence the strength due to the increased amount of cement may be neutralized by the decrease in density, but the possibilities of this depend upon the plasticity of the mortar, the amount of tamping, the character of the sand and the stone, and the gradation of the sizes. Experiments and experience have shown this law to be almost mathematically exact.

418. Methods of Proportioning. There are four methods in more or less general use for proportioning concrete, which may be briefly designated as follows: (1) by arbitrary assignment; (2) by voids; (3) by trial; and (4) by sieve-analysis. These methods will be considered separately in the above order.

419. Proportioning by Arbitrary Assignment. This is the least scientific method of proportioning, it virtually assumes the relations as a matter of judgment, without much, if any, consideration of the character of the aggregate; that is, the proportions are assigned without any reference to the fineness or coarseness of the sand and the stone, or to the gradation of the sizes of each.

420. Proportioning by Voids. To determine the best proportions for any particular sand and aggregate, find the per cent of voids

in the sand and in the stone, and use enough cement paste to fill the voids in the sand and enough mortar to fill the voids in the coarse aggregate. Owing to the errors in using this method, and particularly in getting the cement paste to fill the voids of the sand and the mortar to fill the voids of the stone, this method is not very practical.

421. Proportioning by Trial. The second law in § 417 leads to a simple method of finding the best relation of the sand and the stone. According to that law that combination of sizes of sand and stone which with a constant quantity of cement gives the least volume of concrete is the best.

To apply this method procure a vessel of uniform cross section, say a cylinder, 10 or 12 inches in diameter and 12 or 14 inches deep, its strength being such that its volume will not be changed in tamping it full of concrete. Weigh out a unit of cement, and any number of units of sand, say two, and also weigh out any number of units of broken stone, say five, taking care that the quantities are such that when the ingredients are thoroughly mixed and placed in the cylinder, the mixture will fill it only partly full,—say three quarters full. Make a concrete of any desired consistency by mixing the cement, sand and stone with water on a sheet of steel; tamp the concrete into the cylinder leaving the upper surface smooth and horizontal, and then measure the depth of the concrete from the top of the cylinder. Next empty the concrete from the cylinder, clean it and the tools; and then make another batch with different proportions of sand and stone, keeping the quantity of cement and the plasticity of the concrete the same as before. If this batch when tamped into the cylinder gives a less volume of concrete, this proportion is better than the first. Continue the trials until the proportion has been found which will give the least depth in the cylinder.

422. Proportioning by Sieve Analysis.* "Sieve analysis consists in separating the particles or grains of a sample of any material—such as broken stone, gravel, sand or cement—into the various sized particles of which it is composed, so that the material may be represented by a curve each of whose ordinates is the percentage of the weight of the total sample which passes a sieve having holes of a diameter represented by the distance of this ordinate from the origin

* This method of proportioning the sizes of the sand and stone in concrete was devised by Wm. B. Fuller, and is described by him in detail on pages 183–215 of Taylor and Thomson's Concrete Plain and Reinforced (1909 edition), from which these extracts are taken by permission of the authors.

in the diagram." The line *DBKLA*, Fig. 73, is a typical sieve-analysis curve for crusher-run micaceous-quartz stone; and the line *OF* represents a fine sand.

" The objects of sieve-analysis as applied to concrete aggregates are: (1) to show graphically the sizes and relative sizes of the particles; (2) to indicate what sized particles are needed to make the aggregate more nearly perfect, and so to enable the engineer to improve it by the addition or substitution of another material; and (3) to afford means for determining the best proportions of different aggregates."

" The experience which the writer [Fuller] has had and the various experiments which he has made indicate that concrete which works

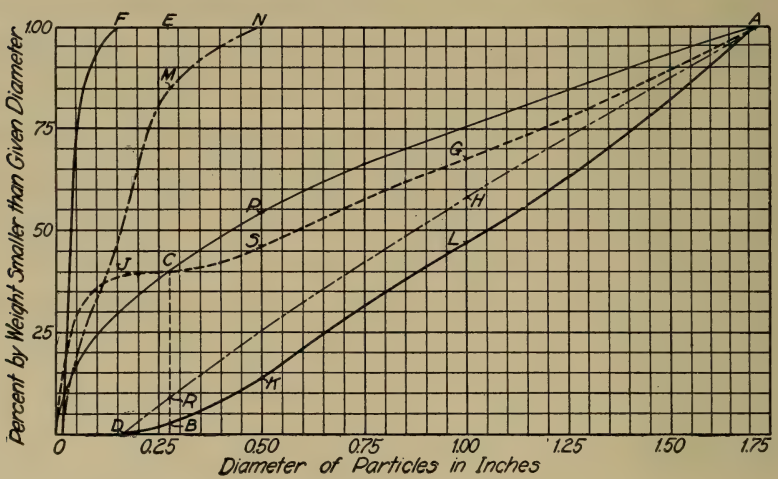

FIG. 73.—SIEVE-ANALYSIS CURVE.

the smoothest in placing and gives the highest breaking strength for a given percentage of cement, is made from an aggregate whose sieve analysis, taken after mixing the sand and the stone, forms a curve approaching a parabola having its beginning at the zero of co-ordinates and passing through the intersection of the curve of the coarsest stone with the 100 per cent line, that is, passing through the upper end of the coarsest stone curve." In Fig. 73, the parabola *OCPA* represents a theoretically perfect combination of sizes of sand and stone all of whose pieces pass a $1\frac{3}{4}$-inch screen. This curve shows, for example, that for the best combination of the above materials 93 per cent of the mixture should pass the $1\frac{1}{2}$-inch sieve, 76

per cent should pass the 1-inch sieve, 54 per cent the $\frac{1}{2}$-inch, and so on."

"Where, as in Fig. 73, the materials to be mixed are represented by only two curves no combination of which will make a curve as close to a parabola as is desirable, there is another limiting condition which was brought out by the experiments, viz., that for the best results the combined curve shall intersect the parabola on the 40 per cent line, at C, and that the finer material shall be assumed to include the cement."

423. The curve $DBKLA$, Fig. 73, may be transformed so that it will pass through C, by changing the distances from the top of the diagram to the line $DBKLA$ in the proportion $\frac{EC}{EB} = \frac{60}{98} = 61$ per cent, which shows that 61 per cent of the dry materials should be broken stone. In a similar manner the line OF is re-plotted in the position OJ. The line $OJCGA$ is assumed to represent the best possible combination of sizes of this sand and stone. For example, with the best possible combination of sizes of this stone and sand, 89 per cent would pass the $1\frac{1}{2}$-inch sieve, 67 per cent would pass the 1-inch sieve, 46 per cent the $\frac{1}{2}$-inch sieve, and so on.

"The proportion of cement to be used to give the required strength of concrete must always be assumed; and in this example it will be assumed that the cement is to constitute one eighth of the dry materials (measured before the sand and stone are mixed together), which will make the cement one ninth or 11 per cent of the total dry materials. Since the diagram shows that the sand and cement are to constitute 39 per cent of the dry materials, the sand must then be $39 - 11 = 28$ per cent."

"The proportions of concrete for 1 part cement to 8 parts of sand and stone, measured separately, then are: 11 per cent cement, 28 per cent sand, and 61 per cent broken stone, or 1 : 2.5 : 5.5 by weight. If the proportions are required by volume and the relative weights of the sand and the stone differ from their relative volumes, the proportions should be corrected accordingly."

424. "An important feature of the sieve-analysis curves is that they show how the materials may be improved by adding or subtracting some particular size. For example, if the stone represented by the curve $DBKLA$ in Fig. 73 had contained more pieces 0.5 and 1.0 inch in diameter, its curve would have more nearly approached the parabola in the region SG. If a stone giving the line $DRHA$ were used, the ratio for transforming the line to make it

pass through C would be $\frac{EC}{ER} = \frac{60}{91} = 66$ per cent, which shows that with the assortment of sizes of broken stone represented by this line the best concrete is made by using 66 per cent of broken stone. For a 1 : 8 mixture as before, the proportions would be 11 : 23 : 66, or 1 : 2 : 6,—a cheaper, stronger, and denser concrete than that made with the stone represented by the line *DBKLA*."

For further details concerning this method and for later slight modifications in the form of the ideal sieve-analysis curve, see Taylor and Thompson's book mentioned above or the author's Treatise on Masonry Construction.*

"This method affords a means of determining the best proportions in which to mix the fine and coarse aggregate, and also shows how the aggregate may be improved by adding or subtracting some particular size. Sieve analyses can be made from time to time as the work progresses to see whether or not the sizes of the aggregate have changed; and if the sizes have changed, the proportions can be varied to secure the most economical and the densest concrete. In a work of any magnitude the greater labor required in determining the proportions by sieve-analysis curves is likely to be justified by the better quality, or the less cost, of the concrete; and the extra labor required to make sieve analyses during the progress of the work will be worth all it costs because of the better control of the proportions of the concrete.

"To secure the maximum benefit of this method of proportioning, it is necessary to screen the aggregate to several sizes and then combine them in the proportions indicated by the sieve-analysis curve. As to whether or not the increased cost of screening and proportioning would be justified by the saving of cement, depends upon the magnitude of the work and other conditions. The following example illustrates the possibilities:

"The ordinary mixture for water-tight concrete is about 1 : $2\frac{1}{2}$: $4\frac{1}{2}$, which requires 1.37 barrels of cement per cubic yard of concrete. By carefully grading the materials by the methods of sieve analysis the writer [Fuller] has obtained water-tight work with a mixture of about 1 : 3 : 7, which requires only 1.01 barrels of cement per cubic yard of concrete. This saving of 0.36 barrel is equivalent, with portland cement at $1.60 per barrel, to $0.58 cubic

* For an explanation of the advantages of plotting sieve-analysis curves on logarithmic cross-section paper, and of an ingenious use of the method, see *Engineering and Contracting*, Vol. 47 (1917), p. 230.

yard of concrete. The added cost of labor for proportioning and mixing the concrete because of the use of five grades of aggregate instead of two, was about $0.15 per cubic yard, thus effecting a net saving of $0.43 per cubic yard."

425. DATA FOR ESTIMATES. Portland Cement. Portland cement, which is now practically the only cement used in engineering construction, is usually shipped in cloth bags containing 94 lb. each. The cement is usually sold by the barrel, which is considered as four bags. In computations involving the proportions for concrete, a bag is usually considered as containing one cubic foot of packed cement.

Until the disturbance of prices by the Great European War the price of portland cement at any place east of Omaha, Nebraska, was from $1.50 to $1.75 per barrel in cloth bags, the bags being charged at 10 cents each and undamaged bags being returnable at that price.

426. Sand and Gravel. Before the Great European War the price of washed, screened, and graded sand at the pit was about 25 cents per ton; and of washed, screened, and graded gravel, about 35 cents per ton. The freight was about 47 to 48 cents per ton per 100 miles in each case.

427. Broken Stone. Before the disturbances of prices by the Great European War, the price of crushed limestone, screened and graded, f.o.b. the quarry, was about 55 cents per ton; and the freight was about 47 to 48 cents per ton per 100 miles. Limestone, graded and loaded into a freight car weighs about 2500 lb. per cubic yard.

The cost of crushed trap f.o.b. the quarries in New Jersey for several years previous to 1900, was 40 to 50 cents per ton (about 50 to 62 cents per cubic yard); but in that year the price was increased nearly 50 per cent. In Massachusetts, the cost of broken trap on cars at the end of the railroad transportation, varies from $1.10 to $1.60 per ton (about $1.32 to $1.93 per cubic yard). In Boston, the cost of crushed granite delivered on the streets is $1.65 to $1.90 per ton. In Montreal, syenite delivered on the streets costs an average of $1.15 to $1.20 per ton.

428. Ingredients for a Cubic Yard. Table 28, page 236, shows the quantities of cement, sand, and stone required for a cubic yard of concrete of different proportions, using three grades of broken stone or gravel. The concrete was mixed wet but not soupy; and was also mixed very thoroughly. If it had been mixed drier or less

TABLE 28

Ingredients Required for a Cubic Yard of Wet Concrete *

1 cubic foot of packed cement assumed to weigh 100 lb.

Proportions by Volumes.			Scientifically Graded Stone.			Unscreened Stone.			Screened Stone.		
			Size 2″ to 0.20″. Voids 20%.			Size 2″ to 0.20″. Voids 30%.			Size 2″ to 1″. Voids 50%.		
Packed Cement.	Sand.	Loose Stone.	Cement, *bbl.*	Sand, *cu. yd.*	Stone, *cu. yd.*	Cement, *bbl.*	Sand, *cu. yd.*	Stone, *cu. yd.*	Cement, *bbl.*	Sand, *cu. yd.*	Stone, *cu. yd.*
1	1	2	2.26	0.32	0.64	2.43	0.34	0.68	2.62	0.37	0.74
		3	1.77	0.25	0.75	1.93	0.27	0.82	2.12	0.30	0.90
1	$1\frac{1}{2}$	2	2.03	0.43	0.57	1.76	0.37	0.74	2.31	0.49	0.65
		3	1.63	0.34	0.69	1.48	0.31	0.83	1.91	0.40	0.81
		4	1.39	0.29	0.77	1.61	0.45	0.68	1.63	0.34	0.92
1	2	3	1.50	0.42	0.63	1.61	0.45	0.68	1.89	0.53	0.80
		4	1.27	0.36	0.72	1.38	0.39	0.78	1.65	0.46	0.93
		5	1.10	0.31	0.77	1.20	0.34	0.84	1.47	0.41	1.03
		6	0.97	0.27	0.82	1.06	0.30	0.89	1.32	0.37	1.11
1	3	4	1.12	0.47	0.63	1.21	0.51	0.68	1.42	0.60	0.80
		5	0.99	0.42	0.70	1.07	0.45	0.75	1.28	0.54	0.90
		6	0.88	0.37	0.74	0.96	0.41	0.81	1.16	0.49	0.98
		7	0.80	0.34	0.79	0.87	0.37	0.86	1.07	0.45	1.05
		8	0.73	0.31	0.82	0.80	0.34	0.90	0.99	0.42	1.11
1	4	5	0.90	0.51	0.63	0.96	0.54	0.68	1.13	0.64	0.68
		6	0.81	0.46	0.68	0.87	0.49	0.73	1.04	0.59	0.88
		7	0.74	0.42	0.73	0.80	0.45	0.79	0.96	0.54	0.95
		8	0.68	0.38	0.77	0.74	0.42	0.83	0.90	0.51	1.01
		9	0.63	0.35	0.80	0.68	0.38	0.86	0.84	0.47	1.06

* From Taylor and Thompson's Concrete Plain and Reinforced, Second Edition (1909), p. 231, by permission.

thoroughly, it would have been less dense, and consequently less quantities of materials would have been required to make a yard.

Data like that in Table 28 are affected by the fineness of the cement, the fineness and dampness of the sand, the kind and coarseness of the stone, the proportions of the several sizes of sand grains and stone fragments, the thoroughness of the mixing, the amount of tamping, etc.; and different experimenters have obtained widely different results. Most experimenters obtain a less quantity because the concrete is mixed drier and entrains more air, and hence is less dense.

429. Fuller's Rule. The following rule, devised by Wm. B. Fuller,* gives the quantities of cement, sand, and stone required to make a cubic yard of concrete; and is fairly representative of all classes of materials. This rule is valuable because it is so simple that it can be carried in the memory.

c = number of parts of cement.
s = number of parts of sand.
g = number of parts of gravel or broken stone.
C = number of barrels of packed portland cement required for 1 cubic yard of concrete.
S = number of cubic yards of loose sand required for 1 cubic yard of concrete.
G = number of cubic yards of loose gravel or broken stone required for 1 cubic yard of concrete.

$$C = \frac{11}{c + s + g};$$

$$S = C \times s \times \frac{3.8}{27};$$

$$G = C \times g \times \frac{3.8}{27}.$$

"If the coarse material is broken stone screened to uniform size, it will contain less solid matter in a given volume than average stone, and hence about 5 per cent should be added to quantities of all three ingredients as computed by the above rule. On the other hand, if the coarse material is well graded in size, about 5 per cent may be deducted from all of the quantities."

* Taylor and Thompson's Concrete Plain and Reinforced, Second Edition, p. 16.

The preceding formulas are sometimes modified by changing the constants 11 and 3.8. For example, one engineer substitutes 9.5 for the 11, and 4 for the 3.8.

Art. 2. The Construction

431. Drainage. The drainage of the road-bed of a concrete road or pavement is of vital importance. If the subgrade is not well drained, there is danger that after the concrete is laid, the drying of the soil under the edges of the concrete may permit the pavement to settle and thus cause longitudinal cracks on the surface. Further, if the subgrade is not well drained, there is a possibility that the frost may lift the edges of the concrete roadway and cause a longitudinal crack,—at least on the lower side. With some forms of roads a crack in the surface will heal under travel; but a crack in a concrete pavement not only can not heal under travel, but will continually enlarge. There is no part of the work of the construction of a concrete road or pavement that is more worthy of intelligent care and painstaking labor than the preparation of the subgrade; and the slight additional cost necessary to insure good results is abundantly justifiable.

If the soil is sandy, there is a probability that the natural underdrainage is sufficient for the purpose.

If the soil is only moderately retentive, a shallow longitudinal ditch should be constructed just outside of the edge of the concrete slab. The ditch should extend about 8 or 10 inches below the surface of the road-bed, i. e., below the bottom of the concrete slab; and should be filled with coarse gravel or broken stone. From this longitudinal ditch short transverse trenches should be dug across the shoulder to the ditch at the side of the roadway. These transverse trenches should have a grade sufficient to permit them to carry the water promptly and completely to the side ditch. In particularly retentive soil, these transverse trenches should not be placed more than 50 feet apart. On the level stretches, these transverse trenches should be practically at right angles to the direction of the road; but if the road is on a grade, they should make an acute angle with the roadway, the amount of this angle depending upon the grade of the road. These lateral ditches should be filled level full with broken stone or coarse gravel to a point at least a little beyond the outer edges of the shoulders and preferably nearly to the bank of the ditch at the side of the roadway.

If the soil is so retentive that the underground water level is likely

to rise within a foot or so of the surface, then a farm tile should be laid on one or both sides of the paved portion. For a discussion of the purposes of underdrainage and the method and cost of laying the tile, see § 114–24 of Chapter III,—Earth Roads. For a discussion of the subject of Side Ditches, see § 125–28.

432. V-Drains. Some engineers employ what is usually called a V-drain, Fig. 74. The subgrade is excavated to a depth below

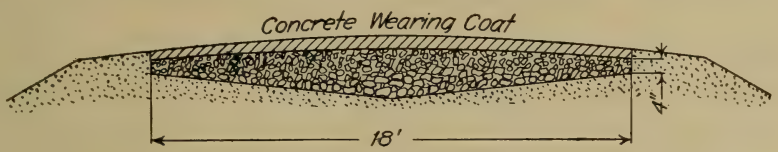

FIG. 74.—THE V-DRAIN.

the base of the concrete slab of 12 to 18 inches at the center and 4 to 6 inches at the side, and this trench is filled with loose stone. The sizes of the stones are usually limited as follows: the largest the equivalent of a 6-inch cube, and the smallest a 2-inch fragment. The largest stones are placed in the bottom of the trench, and no 3-inch stone is allowed within 2 inches of the upper surface of the stone in the trench. After the trench is filled with stones, it is usually rolled with a self-propelling roller, and any depressions that appear are filled with stones.

This form of drain ordinarily costs 50 to 60 cents per linear foot, and is of doubtful economy, unless where bowlders or loose stones abound on or near the road, or where the road is on very wet and retentive soil.

433. PREPARING THE SUBGRADE. The fundamental requirement is that the subgrade shall at all times be of uniform density, so that it will not settle unevenly and cause cracks in the concrete surface.

434. Before the grading is begun, or at least before it is completed, the curbs (Chapter XIV) are built, or the side forms (§ 448) are set, to serve as guides in bringing the subgrade to the proper surface.

435. On Virgin Soil. All brush, trees, stumps, and large roots for a width of 25 feet on each side of the center line of the proposed roadway, should be cut off and be removed from the limits of the right-of-way.* The road should be grubbed for the full width of the

* If the pavement is to be more than 15 feet wide, this quantity is to be proportionally greater.

excavation, and no stumps or large roots should be left within these limits except when a fill of more than 5 feet is called for on the plans, in which case all stumps should be cut off to within 12 inches of the original ground level. Stumps on the cleared portion not within the grubbed limits, should be cut off to within 12 inches of the original ground level. Stumps on the cleared portion not within the grubbed limits, should be cut off not more than 2 feet from the ground.

All soft or spongy spots and all vegetable matter should be removed, and the space be re-filled with suitable material. It is not wise to put any dependence upon the ability of the concrete slab to bridge soft spots. After the subgrade has been brought to the proper surface, it should be rolled with a 3-wheel 10-ton self-propelling roller to disclose any soft spots. Any depressions discovered in rolling should be filled and be re-rolled until no depressions appear. The rolling should be continued until the roller leaves no material track or depression. However, clean dry sand can not be consolidated by rolling; and some plastic clay can be rolled too much.

After the grading is completed, if the natural lay of the ground is such that there are sumps or pockets which hold water, or if such sumps or pockets are made during the progress of the work, they should be thoroughly drained.

436. On Earth Road. If the concrete road or pavement is to be constructed upon virgin soil, that is, if it is not to be constructed on an old road-bed, the precautions described above are sufficient to secure a reasonably good foundation. But if the pavement is to be constructed upon an old road-bed of any kind, great care must be taken in preparing the subgrade. The old road-bed is likely to be more compact in the center than at the sides; and consequently there is danger that the pavement will settle more at the sides than at the center, and therefore will crack longitudinally. Further, it is likely that the traveled way of the old road will not at all places be central under the new pavement; and consequently the latter will settle unevenly and crack.

When the subgrade is an old roadway, since the roller is likely to balance upon the more compact central core and therefore not consolidate the soil at the side of the old roadway, it is not sufficient to roll the subgrade longitudinally. In extreme cases it may be necessary to plow the old road-bed and then harrow it, and finally consolidate the entire new road-bed with the roller.

437. On Gravel or Macadam Road. Not infrequently a concrete slab is constructed on an old gravel or macadam road. There is

considerable difference of opinion as to the wisdom and the method of utilizing the old road. The objections and difficulties are that the old road usually has too much crown; the surface is full of holes; the old road often has an undesirable profile; and the old road is narrower than the new one, and consequently the sides are likely to settle and crack the concrete slab longitudinally. On the other hand, the old road is already in place, is usually well consolidated, and a careful investigation should be made to determine whether it can be economically used.

The first thing is to establish a grade line for the subgrade. This may require the cross sectioning of the old road at frequent intervals,—perhaps each 50 or 100 feet, depending upon the condition of the surface and the regularity of its profile. After having established a grade line, it is usually necessary to scarify the old road in places to remove the high spots. The low places should be filled with gravel or stone to avoid an excessive depth of concrete. The subgrade is then rolled; and if necessary, the low places are again filled and again rolled. The permissible degree of variation of the subgrade from the proposed contour depends upon the relative cost of the labor required in finishing and of the concrete required to fill the low places.

It is particularly important that the side forms for the concrete (see § 448) should be set up, or that the curbs should be built, before the old road is scarified, so they may carry the templet used as a guide in re-shaping the old road.

If the old road is narrower than the new, or not central under it, great care must be taken in consolidating the soil at the edge of the old road. These edges should be covered with gravel or broken stone and be rolled until they are firm and solid.

438. Cross Section of Subgrade. The cross section of the subgrade is made either flat or crowned to conform to the finished surface of the concrete. The former seems to be the better and more common. It is claimed that experience shows that a pavement having a flat subgrade is less likely to crack longitudinally. No entirely satisfactory reason for this has been given; but possibly it is due to the greater tendency of the two portions to separate when the subgrade is crowned.

439. One vs. Two-Course Pavements. Usually the concrete is laid in one course at a single operation; but sometimes, when material suitable for the wearing surface is expensive, and when local but less suitable material is much cheaper, the concrete is laid in two

courses, the lower one of the poorer and cheaper material. The lower course is usually also a little leaner and the top course a little richer than for a one-course pavement. At times such construction may be economical.

On the other hand, the two-course work is objectionable for the following reasons: 1. It is difficult to keep the two classes of material separate. This is more serious on a narrow rural road than on a wide city pavement. 2. There is a possibility of not securing a good union between the two courses. 3. If the lower course is leaner, it will absorb water from the subgrade and expand, while the top course is likely to dry out and contract; and consequently the two are likely to separate. 4. The bottom course absorbs water and expands, and is likely to produce a longitudinal crack.

Good two-course pavements have been laid; but they require more labor and greater care in construction. Statistics show that a little less than 30 per cent of all concrete roads and pavements are two-course work.

All the discussions that follow relate to one-course work.

440. If reinforcement is to be used (§ 469), it is necessary to lay the concrete in two courses and place the reinforcing net between them; but the same mixture is ordinarily used for both courses, and hence such construction is not usually classed as two-course work.

441. Cross Section of Pavement. The cross section of the concrete slab depends upon its width and thickness, and upon the crown of its upper surface.

Fig. 75 shows the cross sections recommended by the 1916 National Conference on Concrete Road Construction, for cuts and for fills. For the recommendations of a committee of the American Society of Civil Engineers concerning crown, see Table 16, page 65.

442. Crown of Surface. In determining the proper crown for a concrete road surface, a distinction should be made between a country road and a city street. The former need be crowned only enough to afford lateral drainage, particularly after the middle is worn down somewhat; while on a city street with side curbs, the crown should be enough to prevent an undue portion of the pavement from being covered with water during a rain.

The only advantage in crowning a road surface is to secure surface drainage, and with perfect work a very small crown would suffice. An excessive crown drives travel to the middle of the road, and con-

sequently does not distribute the wear uniformly over the pavement; therefore the less the crown the better, provided good surface drainage is secured. Some crown is necessary on account of (1) inevitable imperfections in finishing the surface, (2) the accumulation of leaves, twigs, straws, etc., on the surface, and (3) the wear of the pavement.

443. The crown used in practice for concrete roads without curbs, varies from $\frac{1}{24}$ to $\frac{1}{200}$ of the width, without much tendency

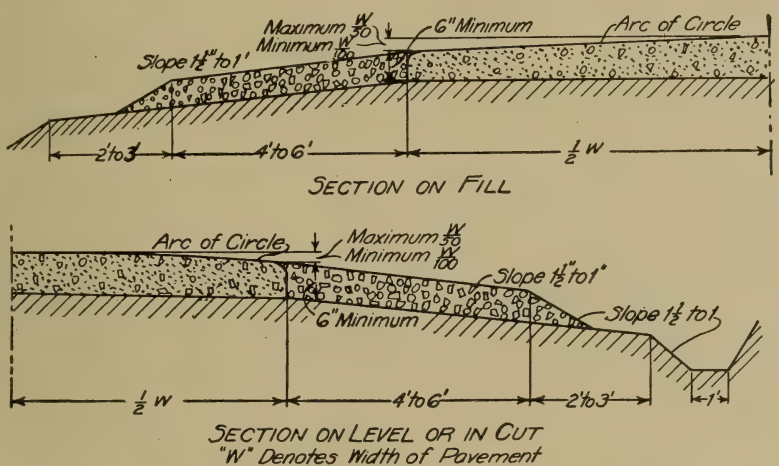

FIG. 75.—CROSS SECTIONS FOR CONCRETE ROADS.

to group withir any smaller limits. For concrete pavements with curbs the crown employed in practice varies from $\frac{1}{50}$ to $\frac{1}{150}$ of the width, the intermediate values being used about equally. The National Conference on Concrete Road Building recommends a crown of $\frac{1}{100}$.

444. Super-elevation on Curves. For a discussion of this subject, see § 90.

445. MAXIMUM GRADE. For a discussion of the general subjects of maximum grades, see § 79–85; and for the recommendations of a committee of the American Society of Civil Engineers concerning maximum grades, see Table 15, page 57. The above committee recommends 8 per cent as the permissible maximum; but numerous examples could be cited of concrete surfaces on steeper grades. For example, Sioux City, Iowa, lays concrete on grades up to 16 per cent, and Mankato, Minn., on 14.3 per cent.

446. WIDTH. For a general discussion of the width of the improved portion of a road, see § 95–6. Both the 1914 and the 1916 National Conference on Concrete Road Building recommended a width of concrete of 10 feet for a single-track road, and 18 feet for a double-track road; and that for roads 18 feet or more in width, it is not necessary to harden the shoulders by applying gravel or broken stone. For a consideration of extra width on curves, see § 97.

447. THICKNESS OF CONCRETE. The proper thickness depends to some degree upon the climate, the width of the slab, the character of the soil, the thoroughness of both the surface and the underdrainage, the degree of consolidation of the subgrade, the proportions and quality of the concrete, the character of the workmanship of every part, the care employed in curing the concrete, and the amount and character of the traffic. These factors are not of equal importance, and the importance of any one item may vary considerably with local conditions.

It is not possible to compute the thickness required in any particular case; and all that can be done toward determining a working rule for the thickness of a concrete road slab, is to accumulate data concerning practice. In studying the results of experience, care should be taken to consider each of the factors mentioned above.

As a rule engineers make the thickness more at the middle than at the sides; but some engineers prefer a uniform thickness, on the theory that traffic is likely to be distributed over the entire surface. Apparently the latter overlook the heaving effect of frost, and also the effect of wear, which is more at the middle than at the sides.

In California, part of which state is classed as semi-arid and part as arid, the State Highway Commission has laid many miles of concrete roads 16 and 18 feet wide and only 4 inches thick, which have given entire satisfaction.

In Oregon, a state that is chiefly semi-arid, many miles have been built 15 feet wide with a thickness of $5\frac{1}{2}$ inches at the sides and $6\frac{1}{2}$ inches at the crown, which competent authority pronounces as being satisfactory. In 1914 three miles of 16-foot roadway were built in which the thickness at the sides was only 4 inches and that at the crown only 5 inches, and in 1917 this road was in excellent condition.

In the Mississippi Valley, the general practice seems to be to make the thickness 6 inches at the side and 7 or 8 inches (usually the latter) at the crown.

448. SIDE FORMS. The concrete is laid between side forms or

curbs. The former is the custom for rural roads, and the latter for city pavements. The forms for curbs or combined curbs and gutters will be considered in Chapter XIV—Curbs and Gutters. For rural roads, planks or steel channels are set at the edges of the concrete slab to retain the concrete, the width of the form boards determining the thickness of the slab. The forms are usually set before the subgrade is brought to its final surface. The tops of the forms are used as guides in finishing the surface of the subgrade, and later are used to guide the template in striking off the the top surface of the concrete.

The forms may consist of 2- or $2\frac{1}{2}$-inch plank or of steel channels. The plank forms should be securely held in place by means of stakes on the outside driven either to such a depth that their tops are below the upper edge of the forms or at such a distance outside of the forms as not to interfere with the operation of the template. The planks should have a continuous bearing on the subgrade, as otherwise they will sag when the concrete is struck off. Adjoining ends of the several planks should be fastened together so as to keep them in line. Fig. 76, page 247, shows plank forms in reasonably good position. Fig. 77, page 247, shows plank forms poorly constructed and poorly set up. In Fig. 77 notice the space under the bottom of the side form; and apparently the forms are not in line either in the foreground or the back-ground.

The steel channels are generally more economical than plank; and are easier set, and keep their place better. They are provided with telescoping joints, which keep the different sections in line; and are hung upon steel stakes previously driven to the right depth, which make it easy to place the forms at the desired grade.

The steel side-forms may be flat and leave a square corner on the upper edge of the concrete slab, or they may have a projection that will leave a beveled edge. However, if the edge of the concrete slab is to be beveled or rounded, it is better to secure this by the use of a finishing tool than by a bevel-edge form.

449. THE CONCRETE. Proportions. The best proportions for any particular materials can be determined only by one or the other methods explained in § 421 and § 422; that is, either by finding by trial the proportions that give maximum density and hence maximum strength, or by sieve-analysis curves.

The proportions originally used are 1 : 2 : 3, 1 : 2 : 5, 1 : 3 : 6, or 1 : $2\frac{1}{2}$: 7. The efficiency of these proportions can not be known unless the gradation of the aggregates is known.

450. The National Conference on Concrete Road Building recommends (for the fine and coarse aggregates specified in § 412 and § 416, respectively) 1 : 2 : 3. The Ohio Highway Department uses 1 : 2 : 4; and the Pennsylvania Highway Department 1 : $1\frac{1}{2}$: 3 or 1 : 2 : 3. The U. S. Office of Public Roads uses 1 : $1\frac{1}{2}$: 3 for gravel or 1 : $1\frac{1}{2}$: 3 for broken stone.

451. Mixing. The ingredients should be mixed, preferably in a batch mixer, until every fragment of the coarse aggregate is covered with mortar and until the concrete is of uniform consistency and color. Ordinarily this can not be accomplished unless all of the materials are in the drum for at least 1 minute and the drum is run at a rate of not less than 12 or 16 revolutions per minute. The time element is as important as the number of revolutions, since time is necessary to allow the water to diffuse through the mass. Some engineers specify that the concrete shall be turned for $1\frac{1}{2}$ minutes. Experiments show the following relation between crushing strength and the time of mixing.*

Crushing strength when mixed $\frac{1}{2}$ minute or 9 revolutions = 1400 lb. per sq. in.
Crushing strength when mixed 1 minute or 17 revolutions = 1587 lb. per sq. in.
Crushing strength when mixed $1\frac{1}{2}$ minute or 26 revolutions = 1924 lb. per sq. in.

The drum must be completely emptied before another batch is added.

452. Fig. 76 shows a typical batch concrete-mixer. In this case the concrete is delivered with a bottom-dump bucket. The bucket should close tightly so as not to leak. Sometimes the concrete is delivered with a tilting bucket. Again, the concrete is delivered through a revolving spout having spiral blades on its inside; and sometimes the mixing of the concrete due to its travel through the tube is offered as an excuse for decreasing the amount of mixing in the drum, but this should not be allowed as in its trip through the revolving spout the concrete is mixed but a little. Sometimes the concrete is delivered by sliding it down a trough; but this is undesirable as the tendency is to mix the concrete too wet, so it will slide freely. Fig. 77 shows a concrete mixer delivering the wearing coat of a two-course concrete road through a gravity spout. Apparently the mixture is much too wet.

The concrete is sometimes transported in wheel-barrows or buggies; but this is objectionable as in the transportation, particularly if

* *Engineering News*, Vol. 75 (1916), p. 768.

the distance is more than 100 feet or if the concrete is quite wet, the coarse aggregate settles to the bottom, and the thoroughness of the mixing is destroyed.

453. Batch mixers are made in various capacities from 6 to 60 cubic feet of concrete; but only those having a capacity from 6 to 30 cubic feet, a 1- to 5-bag mixer, are used in rural-road or city-pavement work. A one-bag or two-bag mixer is the most common, as it is practically impossible in road work to get the material to a larger mixer fast enough to keep it going economically.

The latest models of batch mixers have a loading skip, a device for regulating the time of mix, and an automatic water tank (Fig. 76).

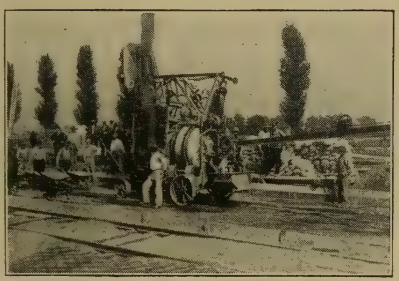

FIG. 76.—CONCRETING CREW AT WORK.

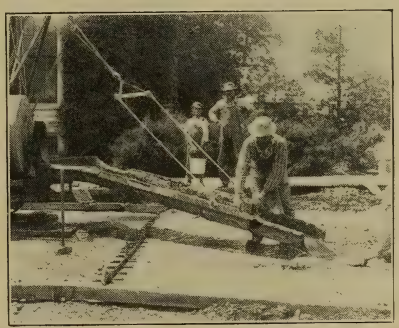

FIG. 77.—DELIVERING THE TOPPING OF A TWO-COURSE CONCRETE ROAD.

454. With continuous mixers it is difficult to control accurately the proportions and the thoroughness of the mixing. Some continuous mixers have devices for automatically measuring the several ingredients, and give fairly satisfactory results when intelligently operated and kept in good order; but ordinarily specifications do not permit the use of a continuous mixer.

455. Whatever the type of concrete mixer, it is wise to check the proportions occasionally, at last once each day, by noting the quantities of the several ingredients used in a certain area of pavement. Since the volume of concrete produced from stated quantities of the ingredients can not be computed accurately, this method is a better check upon uniformity than upon the amount of the ingredients used; but after a little experience with the particular materials and consistency, a real check can be obtained of the amount of the ingredients used.

Fig. 78 shows a form of wheel-barrow used on the Allentown and Eastern concrete road in Pennsylvania, which secures greater accuracy in measuring the ingredients than the usual wheel-barrow having a pressed steel bowl with four curved edges. It can be seen at a glance whether the barrow shown in Fig. 78 is full; while with the form having four curved edges, it is difficult to determine whether the barrow contains the right quantity.

FIG. 78.—BOX WHEEL-BARROW.

456. *Hand Mixing.* Only a few years ago concrete for roads and pavements was usually mixed by hand; but now it is practically all mixed by machine. The output per man with a machine is usually about 50 per cent more than by hand; and the total cost is considerably less by machine than by hand, the exact difference depending upon the thoroughness of mixing in both cases, upon the size and type of the machine, and upon the amount of work per year done with it.

457. *Re-tempering.* The re-tempering of concrete, i. e., the re-mixing of concrete that has partially set, should not be permitted under any circumstances.

458. Consistency. The materials should be mixed with sufficient water to produce a concrete which will hold its shape when struck off with the template. The consistency should not be such as to cause a separation of the mortar from the coarse aggregate in handling. The tendency is to use an excess of water, which facilitates the handling of the concrete, but also tends to separate the ingredients and greatly weakens the concrete.

FIG. 79.—PROPER CONSISTENCY OF CONCRETE.

Fig. 79 shows the proper consistency. With less water the concrete will not flow; and with more water there will be segregation, the mortar flowing to the bottom of the pile. The consistency of concrete is not a sure indi-

cation of its quality, since a given consistency may be produced by using more cement and less mixing, or by more mixing and less cement, or by adding hydrated lime; but nevertheless the above test is a reasonably good one.

459. Placing. If the subgrade has been rutted up in hauling over it, the surface should be restored; and then it should be thoroughly sprinkled, but there should be no pools of water when the concrete is placed. The thorough sprinkling of the subgrade adds materially to the wearing quality of the concrete, by keeping it from drying out too soon.

Immediately after being mixed, the concrete should be deposited to the required depth and width. The section should be completed to a transverse joint without the use of intermediate forms or bulkheads, or a transverse joint may be placed at the point of stopping the work. In case the mixer breaks down, the concrete should be mixed by hand to complete the section.

Where reinforcement is used it should be embedded in the lower course of concrete before the concrete has begun to harden; and the concrete above the reinforcement should be placed within 20 minutes after the placing of the concrete below.

460. The placing of concrete for roads when the temperature is near freezing is not advisable; but if such work is practically unavoidable, the water and the aggregates should be heated before mixing, and the fresh concrete should be protected from freezing for at last 10 days, if the temperature remains near freezing (see § 464). Concrete should never be deposited on a frozen subgrade.

461. Striking. As soon as placed the concrete should be struck off to the established crown and grade by means of a template resting on the side forms and moving with a combined longitudinal and transverse motion. The concrete should have originally been deposited so high that a little concrete will accumulate in front of the template; but this accumulation should not become excessive, and it should be kept nearly uniform along the template by removing the excess with a shovel and throwing it ahead or where needed along the template. As the template approaches a transverse joint most of the excess should be removed.

The template or strike board for a 10- or 12-foot road consists of a 2-inch plank 6 or 8 inches wide cut on the under side to fit a crown slightly in excess of that of the finished surface, and having handles and a shoe to run on the side forms; and for a 14- to 20-foot road,

two 2- by 10-inch planks spiked together. When the pavement is over 20 feet wide a trussed template must be employed.*

462. A variety of devices have been invented to facilitate the striking of the concrete and at the same time to consolidate the

FIG. 80.—HAND-TAMPING TEMPLATES FOR CONCRETE ROADS.

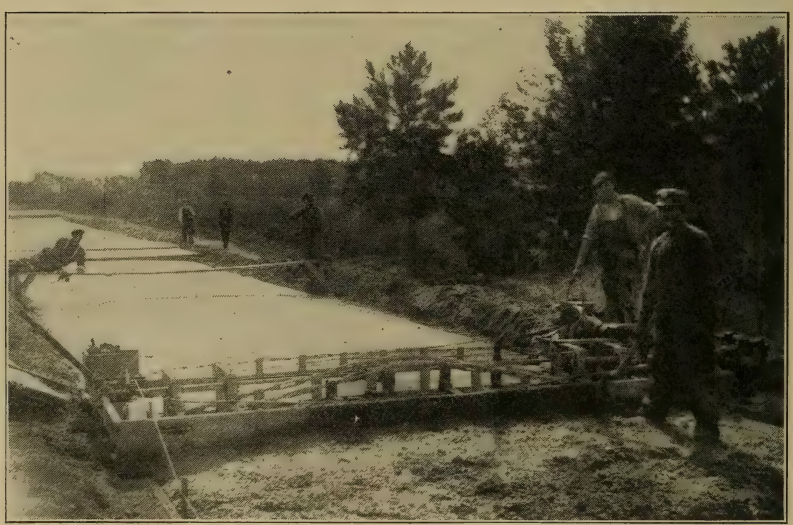

FIG. 81.—BAKER FINISHING MACHINE.

concrete by tamping the surface. One such method consists in first using a template that leaves the concrete a little high, particularly in the center; and then following with a heavy template having a

* For detailed drawings of two templates running on rollers and having levers for raising, and also being adjustable for different widths of pavements, see Proc. 1916 National Conference on Concrete Road Construction, p. 203 and 204.

handle at each end by which it is lifted and dropped at close intervals—see Fig. 80. Another device consists of a self-propelling template and tamping machine running upon the side forms. The front end of the machine strikes the concrete a little high and the rear end tamps it to the right height by an up and down motion of a steel plate extending across the pavement. Fig. 81 shows this machine.

463. Finishing. After the concrete is brought to the established grade and crown with the template, the surface is smoothed or finished, usually with a wood float, the operator working upon a suitable bridge—see Fig. 82. The wood float is better than a

FIG. 82.—BRIDGE UPON WHICH FINISHER WORKS.

metal trowel, since the latter gives a polished surface and also tends to work a film of neat cement to the surface.

The time of finishing has a marked effect upon the wearing quality of the pavement. The tendency is to finish the concrete too soon after placing. The proper time depends upon the weather conditions and the wetness of the concrete when placed. The concrete should not be finished until it is nearly ready to take the initial set; and when in this condition the surface will contain practically no free water, and will be of such a consistency that the wood float will leave distinct marks on the surface. All foreign substances, such as sticks, coal, lumps of clay, etc., on the surface should be removed before finishing.

The surface is sometimes stippled with a broom or stiff brush to

prevent it from becoming slippery, but this is unnecessary; and the making of grooves in the surface is very objectionable even on grades, since the grooves weaken the slab and greatly increase the wear.

Several devices have been invented to facilitate the finishing of the surface. One method is to draw an 8- to 12-inch rubber belt or a rubber-faced canvas belt, or a plain canvas belt back and forth across the pavement after it has been struck off with the template, and to move it along the pavement as the surface is finished. For the best results the surface should be given a second floating just as the cement takes its initial set. When armored contraction joints (§465) are used, it is necessary to do a small amount of hand floating near the joint. The belt finish gives a good surface at small cost.*

The most recent method of finishing the surface is to roll it. The rolling may be done in either of two ways: 1. With a roller about 8 inches in diameter and about 6 feet long, made of light sheet steel and weighing about 70 lb., attached to a long pole, the operator standing at the side of the road and rolling the concrete back and forth across the road. 2. With a roller a little longer than the concrete road is wide, having a round steel axle projecting at each end, the roller being operated by a man on each side of the roadway by means of a suitable handle with a hole in its lower end through which the axle passes. Although first used in 1917, the method of finishing by rolling seems to secure greater strength and density than hand floating; and is rapidly being adopted.

Another method is to draw a rubber garden hose in the form of the letter U along the pavement. Still another method is to draw a 1-inch plank endwise back and forth over the concrete by means of a rope attached to each end. A long-handled float has been used, but opinions differ as to its efficiency.

464. Curing and Protecting. The green concrete may be seriously damaged by the too rapid drying out of the surface in hot or windy weather, or by exposure to low temperature, or by being opened to travel too soon.

If the concrete dries out too rapidly, the surface becomes friable and chalky, and is covered with shrinkage cracks, which are a source of weakness. Therefore in hot or windy weather it is usually necessary to cover the concrete with canvas for at least half a day after it is floated. This canvas is made either in 6-foot strips 2 or 3 feet longer than the pavement is wide, or in long strips a little

* *Engineering News*, Vol. 77 (1917), p. 197–8; or *Illinois Highways*, Dec., 1916, p. 155–56.

wider than the pavement, mounted on rollers. In either case, if the concrete has not set, the canvas should be supported on frames so it will not touch the concrete.

Fig. 83 shows a concrete road protected by canvas. Notice that the earth at the sides of the concrete has been plowed preparatory to covering the concrete with it.

FIG. 83.—CONCRETE ROAD COVERED WITH CANVAS.

When the concrete has hardened sufficiently, the canvas is removed, and the pavement is covered with at least 2 inches of earth which should ordinarily be kept wet for 10 to 15 days. Shavings or straw are sometimes used to cover a new concrete pavement; but they are liable to be washed into piles in sprinkling or to be blown off, in either case leaving exposed patches

If there is danger from frost, the ingredients should be heated before the concrete is mixed (see § 451); and after being placed the green concrete should be protected by canvas or building paper. The former is the easier handled, and is usually more economical. In extreme cases steam may be blown under the canvas or building paper. To protect the concrete after the first night, a layer of straw with a little earth on it has been used.

Great care should be exercised in opening the pavement to travel. The length of time necessary to keep the pavement closed will depend entirely upon weather conditions. During warm weather the pavement should be kept closed to travel for at least fourteen days, and preferably for three weeks. When the conditions are such that the temperature of concrete is less than 50° when placed, hardening takes place very slowly. When a concrete pavement has been laid in the late fall, it is sometimes difficult to determine when it will be safe to open the road. In rare cases it may be necessary, owing to local conditions, to open the road or street before it is absolutely safe. Under such conditions if about 2 inches of straw is placed on the pavement and this is covered with a few inches of earth, the pavement will be protected sufficiently against abrasion to allow the opening of the road sooner than could be safely done without such pro-

tection. This cover will, however, not minimize the danger of damage to the pavement by heavy loads, which will tend to crack a pavement that has not developed its full strength.

465. Contraction Joints. Concrete expands and contracts with changes of temperature and moisture. Since the pavement is ordinarily laid in warm weather, the contraction is likely to be greater than the expansion; and besides the concrete can resist the compression due to expansion better than the tension due to contraction. To prevent the formation of unsightly and irregular cracks due to contraction, it is customary to provide contraction joints at regular intervals. If the pavement has curbs, longitudinal contraction joints also are provided at each curb. Concrete roads and pavements are usually provided with transverse contraction joints from 25 to 75 feet apart, usually about 50 feet.

466. Contraction joints are made in any of three ways: (1) by inserting a wood strip or steel plate, and removing it after the con-

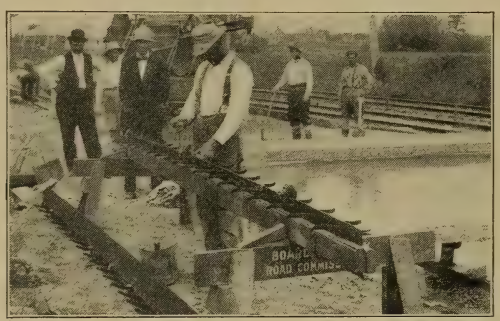

Fig. 84.—Assembling Armored Joint.

crete is in place, and then pouring in an elastic mastic of tar or asphalt; (2) by inserting during construction a sheet of mastic prepared for the purpose; or (3) by inserting one or more thicknesses of tar paper or asphalt felt.

The longitudinal contraction joints are made by placing next to the curb a layer of bituminous mastic from $\frac{1}{2}$ to 1 inch thick, depending upon the width of the pavement.

The transverse joints are sometimes protected by placing a soft-steel $\frac{1}{4}$-inch plate on each side of a $\frac{1}{4}$-inch sheet of mastic. The plates are provided with projections which securely tie or bind them to the concrete. Fig. 84 shows the two metal plates and the intervening sheet of mastic or tar paper being clamped together preparatory

to being set into the pavement. Fig. 85 shows the joint being installed in position in the concrete. Notice that the plates are suspended from a temporary bar which rests on the side forms.

FIG. 85.—INSTALLING ARMORED JOINT.

Fig. 77, page 247, shows an armored joint almost covered with concrete; but notice that there is no temporary supporting bar as in Fig. 77. These protected joints are expensive, complicated to install, and do not wear down with the concrete; and consequently are falling into disrepute.

The most popular joint filler for transverse joints is one or more thicknesses of 3-ply tar paper, which when new projects slightly above the surface of the pavement. Fig. 86 shows the method

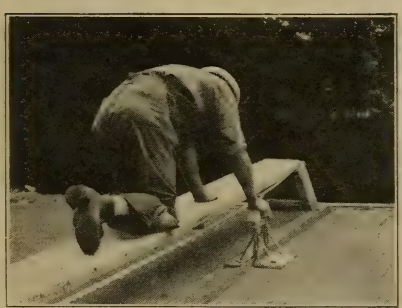

FIG. 86.—FINISHING TAR-PAPER JOINT.

FIG. 87.—TRIMMING TAR-PAPER JOINT.

of finishing the concrete next to one of these joints; and Fig. 87 shows the way of trimming off the surplus tar paper. Some engineers use two thicknesses in hot weather, and three in cool

weather. A single thickness of 3-ply tar paper has been entirely satisfactory. To facilitate the insertion of the tar paper, it is tied with a small string to a steel plate or 1-inch plank thinned a little at its lower edge and cut to the proper width and crown, and the plank and paper are set into place and concrete is deposited on both sides of the plank; and then the strings are cut, the plank and strings removed, and the space occupied by the plank is tamped full of concrete.

It is important that the face of the joint be truly vertical, or there is danger of one slab's sliding up and over the next one

A transverse joint is likely to be a source of weakness owing to the tendency to force an excess of cement, and consequently a deficiency of stone, next to the joint; and also owing to the tendency of the concrete to chip out next to the joint. These tendencies are reduced somewhat by the use of a split float (Fig. 86), which will finish both sides of the joint at the same time.

467. Sometimes the contraction joints are placed at an angle with the length of the road, which is an advantage if there is either an elevation or depression at the joint; but if the joints are properly made and maintained, the extra length is only a needless expense, and besides it is very difficult to strike the surface adjacent to the diagonal joint.

468. A number of attempts have been made to determine mathematically the proper distance between contraction joints; but there is so much uncertainty in each of the several factors of the problem that any such computation is practically worthless. There seems to a growing tendency to narrow the thickness of the joint filler and to lengthen the distance between the joints. Some rural roads have been built without any contraction joints, on the theory that when cracks form they can be filled with pitch. In filling a crack the mastic is piled up over the crack a little to protect the edge of the concrete. Of course, all contraction cracks as well as all others should be kept full of bituminous filler as a part of the maintenance of the road.

469. REINFORCEMENT. Some engineers claim that concrete pavements should be reinforced to prevent cracks due (1) to changes of temperature and moisture, (2) to improper drainage and defective foundation, (3) to insufficient thickness of concrete, and (4) to defective construction. The most simple and most economical method of eliminating each of the three last classes of cracks is to remove the cause. The use of reinforcement simply distributes the

cracks due to changes of temperature and moisture, thus substituting many minute cracks for a few large ones. The large cracks can be protected by filling with tar or asphalt, while the small ones can not be protected, or rather will not be protected, and hence will be a cause of deterioration of the pavement.

It is impossible to compute with any degree of accuracy the amount of reinforcement required to prevent temperature cracks, and much more so to determine the amount required to prevent cracks due to the other causes mentioned in the preceding paragraph. To be most efficient in preventing cracking due to some of the causes, the reinforcement should be near the top of the slab, and for others near the bottom. When reinforcement is used, it is generally placed 2 inches from the top; but when so placed it is not very effective. With the same depth of embedment the reinforcement in a thin broad slab is much less effective than that in a narrow deep beam. Further, the reinforcement is expensive, and is troublesome to install. The reinforcement usually adds 15 to 20 cents per square yard to the cost of the pavement. When reinforcement is used, the concrete must be laid in two courses, which further adds to the expense, and also there is danger that the two courses may not thoroughly unite. Those who professedly use reinforcement primarily to prevent temperature cracks, usually recommend that contraction joints be constructed 75 feet apart; but many concrete roads have been reasonably satisfactory without either reinforcement or contraction joints.

However, reinforcement does serve to keep the parts of the slab from separating after cracks have formed.

It is probably unwise to reinforce a concrete pavement, except perhaps where the slab rests upon spongy soil which it is not practicable to replace, or where it is impossible to obtain adequate drainage. Reinforcement is more common for wide city pavements than for narrow country roads. Only 5 per cent of all concrete roads and pavements laid in this country have been reinforced.

470. SHOULDERS. The shoulders should be partially constructed when the subgrade is prepared; and after the concrete is completed and cured, the shoulder should be finished. It is usual to reinforce the earth shoulder by adding broken stone or coarse gravel, making it 4 to 6 inches thick next to the paved roadway and feathering out to nothing at a distance of 3 to 5 feet out. The shoulders should be thoroughly consolidated by rolling, and should be finished flush with the pavement but not any above it.

Some competent engineers do not strengthen the earth shoulders of double track roads; but this seems of doubtful widsom, because there is always more or less turning off from the pavement, even on double-track roads,—if for no other reason, than that the slow-moving vehicle may give the right-of-way to the fast-moving one, as is required by law in some states.

471. Curbs. A concrete road ordinarily does not have a curb, since it is expected that vehicles will turn off upon the shoulders. When a road is in a cut or upon a hillside, it may be necessary to provide a gutter for drainage. If the road surface is water-bound gravel or water-bound macadam, the gutter must be outside of the

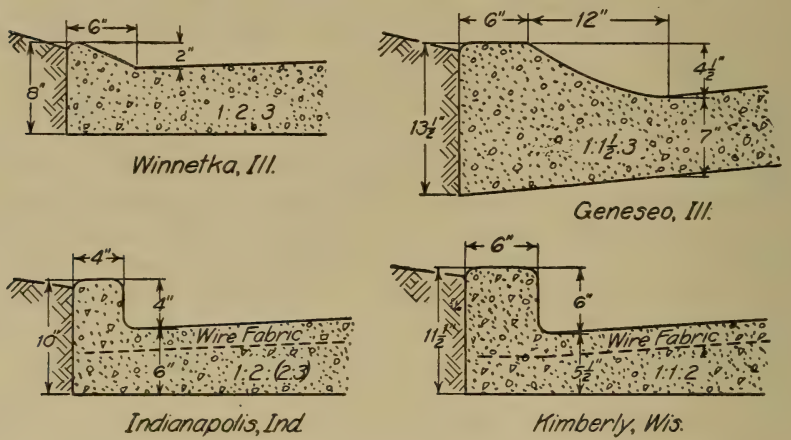

Fig. 88.—Integral Curbs for Concrete Pavements.

paved way, since the flowing water would destroy the road surface; but if the road is a concrete one, flowing water will not damage it, and consequently instead of building a gutter outside of the paved way, it is considerably cheaper to build a curb against or on the edge of the concrete slab, and allow the water to flow down the edge of the concrete slab.

The curb is most cheaply constructed if it is cast at the same time as the slab, and hence is called an integral curb. The integral curb is usually cheaper to build than a durable gutter, and in a cut its use saves considerable excavation.

The integral curb has been used for concrete driveways for a number of years, but was first used for public roads about 1914.

Various forms of integral curbs have been used. The simplest is made by shaping the end of the strike board to form a low curb, but

this form is used only on park drives where a prominent curb is not desired but where a waterway is necessary. The cost of such curbs is nearly negligible.

Fig. 88 shows four types of integral curbs that have been used.* These curbs are constructed by making a form board for the edge of the roadway slab and the back of the curb, and forming the face of the curb by clamping with carpenter's screw clamps a form board against spacing diaphragms. The curbs shown in Fig. 88 are much cheaper to construct than the type of combined concrete curb and gutter used with other forms of pavements—see Chapter XIV.

Fig. 89 shows the from used in integral curb construction in Milwaukee, Wisconsin.† As soon as the pavement is struck off, the form is set in place and weighted with bags of sand to prevent it from rising when the concrete is deposited in it.

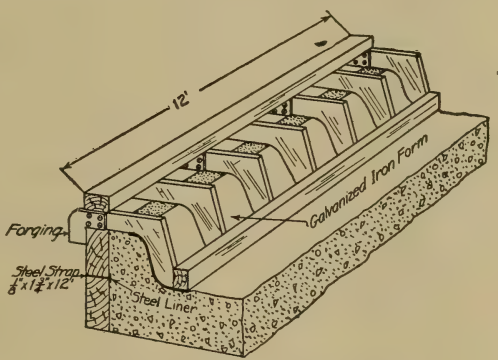

FIG. 89.—FORM FOR INTEGRAL CURB.

The concrete foundation for brick pavements for rural roads were formerly built with integral curbs similar to the last two shown in Fig. 88 except that the corner at both the bottom and the top of the inside face was made square rather than rounded. Strictly speaking the projection on the concrete foundation is not a curb, since it does not project above the pavement. It is usually referred to as an integral curb; but a more appropriate name is concrete edging, which is occasionally used. At present brick pavements for rural roads are usually built monolithic (§ 982),which does away with the need of any curb or edging.

472. COST OF CONCRETE ROAD. The cost of a concrete road-slab varies with the specifications and the local conditions, and hence no record of cost will apply strictly in all cases; but cost data are useful for comparison and as a guide in preparing estimates.

Some of the following cost data are a little out of date; but prices for 1917 are abnormal owing to the disturbance due to the Great European War, and besides any cost data presented in a book of this

* *Engineering Record*, Vol. 71 (1915), p. 111.
† *Engineering and Contracting*, Vol. 45 (1916), p. 544.

character soon becomes out of date. The costs given below are full, and are believed to be accurate and representative. They are interesting chiefly as showing relative values in different localities, and of the different parts of the work. For current prices for concrete roads, consult the construction news in technical journals.

473. Cost of Materials. For data on the cost of portland cement, see § 425; for the same for sand and gravel, see § 426; and for broken stone, see § 427. For more recent prices, see the market reports in current technical journals. For information concerning the amount of the several ingredients required for a cubic yard of concrete, see § 428–29.

474. Cost of Labor. The work of the two following examples of hand and machine mixing was done under substantially the same conditions and hence the results are fairly comparable. Notice that the cost with hand mixing is about a half more than with machine mixing. Further, it is probable that no practicable amount of hand mixing will give as good concrete as ordinary machine mixing; or in other words, if the hand mixing had been as thorough as the machine mixing, the difference in cost would probably have been still greater. Hand mixing has practically been abandoned in concrete road and pavement work.

475. *Hand Mixing.* The construction was two-course work—a 5-inch 1 : 3 : 5 base and a 2-inch 1 : 2 wearing coat; but the cost is not given separately for the base and the top. There were steel-protected contraction joints every 25 feet. The pavement was 30 feet wide.*

Organization.	Cost. Cts. per sq. yd.
1 foreman @ 40¢ per hour	2.10
1 finisher @ 40¢	
1 finisher's helper @ 20¢	
Total for finishing	2.88
1 form setter @ 25¢	
1 form setter's helper @ 20¢	
Total for setting forms	1.76
8 mixers @ 20¢	
1 cement man @ 20¢	
1 man on sand @ 20¢	
4 men on broken stone @ 20¢	
2 spreaders @ 20¢	
Total for mixing and spreading	12.24
1 watchman	0.50
Total for mixing and laying	19.48

* *Engineering and Contracting*, Vol. 38 (1912), p. 710.

476. *Machine Mixing.* The width of pavement was 30 feet. The construction was two-course work,—a 5-inch 1 : 3 : 5 base and a $1\frac{1}{2}$-inch 1 : 1 : 1 wearing coat.*

Organization.	Cost. Cts. per sq. yd.
Base:	
9 men on broken stone @ $22\frac{1}{2}$¢	2.18
3 men on sand @ $22\frac{1}{2}$¢	0.73
1 man at skip @ $22\frac{1}{2}$¢	0.24
1 man wheeling cement @ $22\frac{1}{2}$¢	0.24
1 man leveling concrete @ 25¢	0.27
1 helper leveling concrete @ $22\frac{1}{2}$¢	0.24
1 tamper @ $22\frac{1}{2}$¢	0.24
1 engineer @ 25¢	0.27
1 fireman @ 25¢	0.27
1 bucket operator @ 15¢	0.16
1 water boy @ 5¢	0.05
1 sack boy @ 5¢	0.05
1 foreman @ 45¢	0.48
Total for base	5.43
Wearing Coat:	
4 men on granite chips @ $22\frac{1}{2}$¢	0.48
4 men on sand @ $22\frac{1}{2}$¢	0.48
2 men at skip @ $22\frac{1}{2}$¢	0.24
2 men wheeling cement @ $22\frac{1}{2}$¢	0.24
2 rough spreaders @ $22\frac{1}{2}$¢	0.24
1 fine spreader and tamper @ 25¢	0.13
1 fireman @ 25¢	0.13
1 engine runner @ 25¢	0.13
1 bucket operator @ 15¢	0.08
1 sack boy @ 5¢	0.02
1 water boy @ 5¢	0.02
1 foreman @ 45¢	0.24
1 finisher @ 25¢	0.61
1 finisher's helper @ $22\frac{1}{2}$¢	0.55
Total for wearing coat	3.61
Setting Forms:	
1 man @ $22\frac{1}{2}$¢	0.42
Miscellaneous:	
1 man trimming grade @ $22\frac{1}{2}$¢	0.43
2 men cleaning up sand and stone	0.36
moving machine	1.30
Total for miscellaneous labor	2.09
Grand total	13.50

* *Engineering and Contracting* Vol. 38 (1912), p. 710.

477. Relative Cost of Labor and Materials. The following data are the averages for seven Michigan State-aid roads, eight Wayne Co. (Mich.) roads, and all the concrete roads built by the Illinois Highway Commission in 1912–13.

MATERIALS:	aggregates	27.7 per cent
	cement	21.6 "
	expansion joints and supplies	6.4 "
	Total materials	55.7 "
LABOR		44.3 "
	Total	100.0 "

478. Total Cost. The three examples in Table 29 are believed to be fairly representative.

The values given in Table 30, page 263, are the average of the contractor's costs exclusive of over-head expenses and profits, but inclusive of the preliminary shaping of the surface and the finishing of the earth shoulders; and include representative states.

For more recent data, see the bidding prices in the construction news of current technical journals.

TABLE 29

COST OF ONE-COURSE CONCRETE SLAB FOR ROADS IN ILLINOIS *

DATA AND DIMENSIONS

ITEMS.	McLEAN.	CARLINVILLE.	SPRINGFIELD.
Area of pavement, sq. yd.	5 000	7 111	5 594
Thickness of pavement, inches	6	6.5	7
Width of pavement, feet	45	16	18
Length of haul, miles	0.12	1.5	.12
Cost of cement per bbl.	$1.06	0.98	1.025
Barrels of cement used per sq. yd.	0.29	0.33	0.29
Cost of gravel per cu. yd. f.o.b. destination	$1.25	$1.25	$1.25
Labor, price per hour	0.22	0.225	0.25
Teams, price per hour	0.50	0.50	0.50

COST OF LABOR AND SUPPLIES

ITEMS.	TOTALS.	Per Sq.yd.	TOTALS.	Per Sq. yd.	TOTALS.	Per Sq. yd.
Superintendence	$ 140.00	$0.028	$ 157.50	$0.0220	$ 202.00	$0.0361
Shaping subgrade	307.11	.061	108.70	.0153	343.44	.0415
Loading and hauling-sand and stone	267.34	.053	795.05	.1120	603.50	.1078
Mixing and placing concrete	414.63	.083	700.58	.0986	644.25	.1150
Watchman and miscellaneous labor	110.26	.022	131.46	.0184	383.75	.0686
Cost of sand and stone	1 017.63	.204	741.00	.1050	1 622.01	.2897
Cost of cement	1 547.15	.309	2 307.90	.3246	1 551.17	.2772
Expansion joints	48.67	.010	112.40	.0156	206.74	.0369
Coal, oil, and miscellaneous supplies	30.75	.006	25.00	.0034	119.19	.0213
Forms and other lumber	35.00	.007	31.75	.0047	18.33	.0033
Filling curb expansion joints	45.18	.010	.....	.....	.....	.....
Reinforcing steel	.....	.....	100.00	.0140	.....	.....
Excavation	.....	.....	591.73	.0840	.....	.....
Trimming shoulders	.....	.....	.....	.....	211.38	.0378
Total	$3 964.02	$0.793	$5 803.07	$0.8176	$5 794.76	$1.0352

* Report Ill. Highway Com., 1912, p. 240, 241, and 247, respectively.

TABLE 30

AVERAGE COST PER SQUARE YARD OF CONCRETE ROAD SLABS IN 1915 *

Connecticut	$1.13	Missouri	$1.09
Illinois	1.03	New Jersey	1.23
Indiana	0.98	New York	0.98
Iowa	1.19	Ohio	1.02
Kansas	1.28	Pennsylvania	1.01
Maryland	1.08	Texas	1.15
Massachusetts	0.95	West Virginia	1.03
Michigan	1.10	Wisconsin	1.02
Minnesota	1.11		

479. CHARACTERISTICS OF A CONCRETE ROAD. The characteristics of a well-built concrete road are: 1. It is reasonable in first cost in proportion to its probable durability. 2. It has a low tractive resistance, but gives a good foothold for horses and automobiles. 3. It is free from dust. 4. It is easily maintained. 5. It is reasonably durable when properly maintained. 6. Its only fault is that the color is somewhat trying to the eyes of the user; although the light color is some advantage at night.

480. CONCRETE STREET PAVEMENTS. The preceding discussion has reference primarily to strips of concrete 10 to 20 feet wide for rural roads, since concrete is in more common use for rural roads than for city streets. The same methods without material change can be employed for pavements up to 30 feet wide; but for wider pavements it is necessary to modify the plan in one of two ways as follows: (1) Make a longitudinal joint in the middle of the street and lay half of the street at a time; or (2) insert screeds transversely to the street, and strike the concrete with a straight edge held parallel to the curb.

On a wide street the finishing is done with a belt or a board laid flatwise and reaching half-way across the pavement, the end at the curb being handled by a man and the end at the center being guided by a small rope in the hands of a man standing on the remote curb. The former method is considered the better, since a longitudinal joint is undesirable. Such joints are sometimes protected with steel plates, and should always be covered with tar; but even then a rut is likely to form along them.

Concrete pavements having separate curbs require longitudinal contraction joints at each edge (§ 465–68); but the integral curb (§ 471) eliminates this complication.

* Data collected by the Portland Cement Association.

481. SPECIFICATIONS. Complete specifications for concrete roads are printed by the several State Highway Departments, of which copies may doubtless be had by citizens of the respective states upon request. The Portland Cement Association publishes for gratuitous distribution the specifications adopted by the American Concrete Institute and recommended by the 1916 National Conference on Concrete Road Building, copies of which may be had gratuiously of the Secretary, Portland Cement Association, 111 W. Washington St., Chicago.

ART. 3. MAINTENANCE

482. CHARACTER OF WORK REQUIRED. The work required to maintain the concrete slab is: (1) keep the joints and cracks filled with bituminous cement; (2) fill with bituminous cement any small pits that appear; (3) clean out any holes left where pebbles have

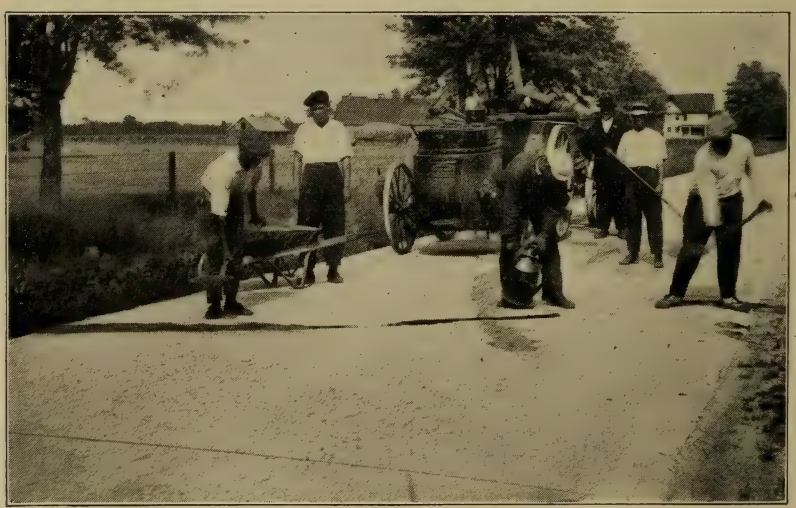

FIG. 90.—FILLING A DIAGONAL CRACK.

been dislodged or where a friable fragment has disintegrated, and fill them with bituminous concrete; and (4) repair any places where the concrete is otherwise defective.

The bituminous material may be either a heavy grade of refined tar or a corresponding grade of asphalt. After the bituminous

material has been applied, its surface should be sprinkled with coarse sand or fine chips of a hard stone.

Fig. 90 shows the method of repairing a transverse contraction joint.

Before being filled, all cracks and joints should be swept clean with rattan or steel brooms. The old tar need not be removed; but any matted earth or other foreign material not removed by the first sweeping should be loosened and removed with a steel hook. It is usually necessary to cover all joints and fill all cracks twice each year.

The pits and the cup-like holes from which pebbles, sticks, etc., have been dislodged, unless early filled, will enlarge rapidly under travel. Where defects of any considerable size are to be repaired, the edges should be made vertical with a chisel and the depth of the hole increased to 1 inch, if it is not already that deep. The hole should be thoroughly cleaned and painted with hot tar; and then be filled with bituminous concrete and sprinkled with coarse sand or fine hard stone chips.

When it is necessary to repair any considerable defective portion of the concrete, the place to be patched should be trimmed and cleaned as described above, and painted with neat cement mortar; and then the hole should be tamped solidly full of good portland-cement concrete. The patch should be kept damp and protected from travel until the cement has fully set.

483. The above method of maintenance will probably serve indefinitely, and will preserve the surface except for the natural wearing away of the concrete by travel.

484. Bituminous Surface. Many attempts have been made to cover the surface of a concrete road with a bituminous coating. This phase of the subject is considered in Art. 2 of Chapter VIII.

485. Cost of Maintenance. The cost of maintenance consists of the annual expense for repairs and the annual contribution to a fund for rebuilding the slab when it is worn out. The introduction of concrete roads is so recent, particularly in proportion to their life, that no reliable data have been accumulated as to the second item of the cost of maintenance. There are reasonably accurate data for the annual cost of repairs, but as a rule there is no information as to amount of or character of the travel on the road; and therefore it is not possible to make any accurate comparisons between such data. Further, no standard has been established as to what constitutes good maintenance; and no system of doing the work has been fully tested.

Apparently the most complete data are those obtained in 1915 by the Illinois Highway Department.* The average annual cost for repairs on 75 miles of concrete rural roads in comparatively short sections, was 0.4 cent per square yard for supervision, labor, equipment and materials. Most of the roads were built in 1914 or 1915. Two methods of maintenance were tried,—(1) by the use of a one-horse wagon drawing a portable heating-kettle, and (2) by an automobile truck carrying a heating tank. By the first method the total cost was 0.32 cent per square yard per treatment, and by the second 0.22 cent. In this work it was found that joints, even though protected by steel plates, required about the same attention as ordinary cracks.

In Connecticut the average cost of repairs to the concrete slab was 0.4 cent per square yard per annum and to drainage 0.3 cent per square yard, or a total of 0.7 cent.

* *Illinois Highways*, August, 1915, p. 118–22; or *Engineering and Contracting*, Vol. 47 (1917) p. 14.

CHAPTER VIII

BITUMINOUS ROAD MATERIALS

486. DEFINITIONS. *Bitumen.* A mixture of native or pyrogenous hydrocarbons and their non-metallic derivatives. It may be a gas, liquid, or solid; and if solid, is soluble in carbon disulphide.

487. *Bituminous Material.* Any material containing bitumen or constituting a source of bitumen. Bituminous coal, peat, etc., are called pyro-bitumens because a bitumen may be produced from them by distillation. The ordinary bituminous materials used in roads and pavements are asphalt, petroleum, and tar.*

488. *Cut-back Product.* A petroleum or tar residuum which has been fluxed with distillate.

489. *Flux.* Fluid oil or tar which is incorporated with asphalt, petroleum, or tar residuum for the purpose of reducing their consistency.

ART. 1. ASPHALT

490. DEFINITIONS. *Asphalt.* Solid or semi-solid native bitumen or solid or semi-solid bitumen obtained by refining petroleum, which consists of a mixture of hydrocarbons and which melts upon the application of heat. Asphalt is usually found associated with various mineral and organic substances. Different varieties of asphalt are called albertite, grahamite, gilsonite, turrellite, uintatite, wurtzelite, etc.

491. *Crude Asphalt.* A native mixture of bitumen, sand, clay, water, organic matter, etc.

492. *Refined Asphalt.* A native mixture after it has been freed wholly or in part from water and organic and inorganic matter by being heated.

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* For detailed explanations of the methods employed in testing bituminous road materials, see Bulletin 314 of the Office of Public Roads and Rural Engineering, U. S. Department of Agriculture, Washington, D. C., 1915.

493. *Rock Asphalt.* A limestone or sandstone naturally impregnated with asphalt. Rock asphalt is the principal form of asphalt used in Europe for paving purposes, and there is usually designated as asphalt.

494. *Asphaltic Cement.* Refined asphalt which has been mixed with some solvent to increase its plasticity, adhesiveness, and tenacity.

495. CHARACTERISTICS OF ASPHALT. As usually found asphalt is of a dark brown or glistening black color. It varies in hardness from a viscous liquid to about $3\frac{1}{2}$ on the Dana scale. When rubbed or freshly broken, it emits a peculiar bituminous odor, and has a slight sour smell. Its specific gravity in the natural state varies from 0.96 to 1.68 according to its porosity and the amount and the character of the impurities present. It is insoluble in water; but is more or less soluble in carbon disulphide, alcohol, turpentine, ether, naphtha, and petroleum.

Asphalt has an appearance somewhat like coal tar. The principal method of distinguishing asphalt from coal tar, available to the layman, is the odor. The tar emits a sharp, acrid odor; while both the crude and the refined asphalt when cold give a weak clay-like odor, and must be rubbed to obtain the distinctive bituminous odor. If tar is mixed with asphalt, the presence of 25 per cent will be revealed by the odor. When being laid in a road or pavement, tar gives off a bluish vapor, while asphalt emits a white vapor.

496. Asphaltic limestone, when freshly broken, varies in color from chocolate brown to black, the color being darker as the proportion of asphalt is greater. The percentage of asphalt permeating the limestone varies in different deposits and in different parts of the same mine, usually ranging from 1 to 20 per cent.

Asphaltic sandstone contains from 1 to 70 per cent of asphalt. The grain is sometimes dense and sometimes porous, sometimes very fine and sometimes coarse.

497. SOURCES OF ASPHALT. Liquid asphalt, or maltha as it is usually called, is found in large quantities in California; but solid or natural asphalt is not found to any great extent in the United States. The principal kinds of the natural asphalts used in this country are: Trinidad, Bermudez, and California.

498. Trinidad Asphalt. The Island of Trinidad, near the northeast coast of Venezuela, South America, supplied something like 90 per cent of all the asphalt used in the world from about 1875 to 1900; and at present the Island of Trinidad is the main source of supply of the native asphalt used in the United States. In south-

west corner of the Island is the so-called pitch-lake, which has an area of about 115 acres. The surface of the lake has an elevation of 138 feet above the sea-level, and near the center the asphalt has a depth of 78 feet. As a rule the surface of the asphalt is sufficiently hard that teams may be driven over it; but the whole mass is in constant motion around several vortices, as shown by trunks of trees which rise and after a time again disappear. Excavations made during the day close up during the night.

The asphalt is excavated with picks and shovels, conveyed to the shore in carts, and lightered to vessels off-shore. On the sea voyage it becomes compacted into a solid mass and must be again broken up with picks. The crude asphalt is mixed with much earthy and a little vegetable matter and water, and is dark brown.

The crude material is refined by placing it in kettles or open tanks and heating it for three or four days, during which time the water is evaporated, the vegetable matter rises to the surface and is skimmed off, and the earthy material settles to the bottom. Great care is required in the refining process not to heat the apshalt to a point where chemical changes take place. The refined asphalt must be softened by the addition of some fluxing material before it is ready for use in the pavement.

499. Bermudez Asphalt. A lake in the State of Bermudez, Venezuela, South America, supplies large quantities of asphalt. The crude asphalt consists of bitumen mixed with sand, clay, and vegetable matter; and is refined in the same way as Trinidad asphalt, but more rapidly, since it contains less water and mineral matter.

500. California Asphalt. California is the principal producer of asphalt in the United States; and is said to have not only larger quantities of asphalt than any other equal area in the world, but a greater variety of forms—solid and liquid asphalt, and asphaltic limestones and sandstones—and in more localities. Maltha (" liquid asphalt ") is found chiefly at Carpinteria, Santa Barbara County, near the sea shore; and solid asphalt is found at La Patera, Santa Barbara County, also near the sea shore. Asphaltic limestone and sandstone are found at a number of places in California, in all degrees of richness and consistency. The principal deposits are at Santa Cruz, San Luis Obispo, and Kings City. The asphalt is extracted from the stone by heating the mass in a tank and drawing off the liquid asphalt.

501. The base of the California petroleums is asphaltic, as distinguished from the paraffin base of the eastern oils; and the process

of refining petroleum leaves the asphalt or maltha as a residue, and at several places asphalt is produced in this way from crude petroleum.

502. Petroleum Residue. Some crude petroleums on distillation have an asphalt residue (see § 547). Three fourths of all the asphalt used in the United States is obtained from asphaltic petroleums. Such material is usually called oil asphalt.

503. Other American Asphalts. Considerable asphalt is shipped to the United States from mines at Inciarte and La Paz, State of Zulia, Venezuela, South America. It is usually called Maracaibo asphalt from the gulf and lake of that name near the mines.

Asphalt is found in much smaller quantities, but sufficient to be of considerable commercial importance, in Utah, Colorado, Indian Territory, Texas, and Kentucky. One of the most important of these is Gilsonite, a solid and nearly pure native bitumen found in Utah and Colorado.

Several deposits of natural asphalt exist in Cuba and along the Gulf Coast of Mexico.

504. SHIPPING ASPHALT. Refined asphalt is shipped in barrels or metal drums or in tank cars. Fig. 91 shows the method of unloading asphalt binder from the tank car to the machine which distributes it upon the asphalt-bound macadam road. In the left foreground is the motor-truck distributor, and behind it is a portable heater for heating the asphalt. Notice that the tank is covered with blankets.

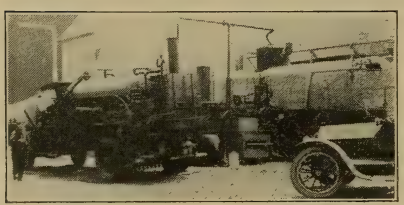

FIG. 91.—UNLOADING ASPHALT BINDER.

505. DESIRABLE PROPERTIES OF ASPHALT. The characteristics required in an asphalt differ according to the purpose for which it is to be used; but in general any asphalt for use in roads or pavements should have the following properties: 1, chemical stability; 2, freedom from decomposition products; 3, binding power; 4, resiliency, and 5, waterproofness.

Apparently it is impossible to devise any tests to measure directly some of these properties; and the difficulties of devising a series of tests is increased by the variation in the character of the different materials.

506. Chemical Stability. The chemical stability of a bituminous

vement is indicated somewhat by the extent to which the material is volatilized under standard temperature conditions. The hardening of the bituminous cement due to evaporation and oxidation is determined by making penetration tests before and after volatilization. The temperature at which the material gives off vapor enough to ignite gives further indication of chemical stability.

507. Freedom from Decomposition Products. If the refining process has been carried on at a too high temperature, the cement may have been partially decomposed. This condition is indicated by the amount of free carbon and other decomposition products that are separated by certain solvents. If the material is a fluxed natural asphalt, these tests throw some light upon the character of the flux.

508. Binding Power. It is important that the bituminous material shall have cementing or binding power, particularly at summer temperatures. There is no single test for this property. The ductility test gives some indication concerning cementing value.

509. Resiliency. It is important that the bituminous cement shall have the power to absorb shock and thus prevent the blow of the wheel or the hoof from destroying the road or pavement surface. This requires that the cement shall have resiliency and malleability, which depend somewhat upon consistency.

510. Waterproofness. The bituminous material should be waterproof so as to prevent water from penetrating the body of the road and doing damage by freezing or softening the subgrade.

511. Tests of Bituminous Materials. Below are the tests usually applied to bituminous materials, and a brief statement of the significance of each. All of these tests (§ 512–27) are applied to asphalts, but only the first eight (§ 512–19) are applied to oils and tars.*

512. Foam Test. This test is applied to asphalts and tars to determine the presence of water. Water is chiefly objectionable since it makes the material difficult to handle when heated above the boiling point of water, because the steam makes the oil or tar foam or froth.

513. Specific Gravity. This test is valuable mainly as a means of

* For a detailed account of the method of making the tests and also illustrations of the apparatus used, see Bulletin 314 of the U. S. Department of Agriculture, December 10, 1915, or Hubbard's Laboratory Manual of Bituminous Materials, 8vo, p. 159, John Wiley & Sons, New York, 1916; and for a description of the tests see Proc. Amer. Soc. of Civil Engineers, December, 1914, p. 3036–50.

identifying the material; but in connection with other tests it is sometimes serviceable in determining the suitability of a material for road purposes. The specific gravity of crude asphalt varies from 1.04 to 1.40, and asphaltic cement from 0.96 to 1.06. The specific gravity of crude petroleum varies from 0.73 to 0.98, the paraffin oils being the lowest and the asphaltic the highest. The specific gravity of crude tar varies from 1.00 to 1.22, the water-gas tars ranging from 1.00 to 1.10, and the coal tars from 1.10 to 1.22. The specific gravity of tar depends chiefly upon the amount of free carbon it contains, the higher the specific gravity the greater the percentage of free carbon. Refined tar has a higher specific gravity than crude tar, partly because the light hydrocarbons and the water have been driven off.

514. Flash Point. The flash point is determined by either the open-cup or the closed-cup method, the latter being the more accurate. This test is mainly valuable as a quick means of differentiating between heavy crude oils and cut-back products; but it also indicates the temperature at which a refined oil has been distilled. Crude paraffin oils usually flash lower than crude asphaltic oils.

515. Consistency. The consistency of a bituminous material is an important factor, since it determines the grade of material suitable for a particular use, and since this test is a means of securing uniformity in the product.

There are three methods or instruments in common use for determining consistency, viz.: the Engler viscosimeter, the New York Testing Laboratory float apparatus, and the penetrometer.

516. *Viscosity.* The viscosimeter determines the viscosity, i. e., time required for a specified amount of the material to flow through a standard aperture. This test is generally used for liquid bituminous materials.

517. *Float Apparatus.* This apparatus determines the time for a specified quantity of semi-solid or solid material to flow through an aperture; and is generally used for semi-solid and solid tars and pitches.

518. *Penetration.* The penetrometer determines the distance a needle will penetrate the material in a specified time. Of course, the size of the needle, the weight on the needle, and the temperature of the material are carefully standardized. The penetration is usually stated in tenths of millimeters; but sometimes in degrees, since the index finger sweeps over an arc of a circle graduated to degrees. This apparatus is generally employed for asphalts; but it is not used

for tars, because the surface tension and the presence of free carbon considerably affect the results without materially affecting the consistency.

519. Melting Point. The determination of the melting point is mainly of value as a means of identification. It is virtually a test of consistency (§ 515). As a rule as the melting point of a bituminous material rises, it becomes harder and more brittle. One of the characteristics of asphalt which peculiarly fits it for use in roads and pavements is that it has a high melting point without being brittle. Paraffin also has a high melting point, but it is brittle.

520. Loss by Evaporation. This test determines the amount of volitilization under standard conditions. The residue is usually tested for penetration, melting point, and ductility. The comparison of the results of these tests before and after the evaporation test determines the amount of hardening, which is an indication of the stability of the cement.

521. Distillation. The distillation is carried on at considerable lower temperatures than the evaporation test, and is usually applied only to tars. The melting point of the residue is determined, and also its consistency at several temperatures. This is an important test of tars to determine their road-building qualities and also their method of preparation.

522. Bitumen Soluble in Disulphide. It is usually assumed that all matter soluble in cold carbon disulphide is bitumen. Fluid oils are almost wholly soluble in this material. The amount and character of the insoluble matter are of most interest in this test. The insoluble matter is usually free carbon, which is of no value in road work. The failure to pass this test is an indication that the material has been overheated, i. e., " cracked."

523. Bitumen Soluble in Naphtha. This test is chiefly valuable in determining the amount of body-forming hydrocarbons in oil and oil products. " No oil having less than 4 per cent insoluble in naphtha will be of service in road work except as a dust preventive." Bitumens insoluble in naphtha are commonly called asphaltenes, while those soluble are called malthenes.

524. Bitumen Soluble in Tetrachloride. The test is made for purposes of identification and also to determine whether the material has been over-heated in the process of manufacture. The bitumen insoluble in carbon tetrachloride but soluble in carbon disulphide is commonly called carbenes.

525. Fixed Carbon. The amount of fixed carbon shows much

the same results as the bitumen insoluble in naphtha. The amount of fixed carbon present is an indication of the mechanical stability of a road oil. Paraffin oils have only little fixed carbon, while asphaltic oils have more, and asphalts still more. This test can not be applied to tar, owing to the error introduced by the presence in it of considerable free carbon.

526. Ductility. This test consists in forming a briquette of the material and observing the amount of elongation before rupture. It is the only test for determining the cementing value of an asphalt, and hence is very important.

527. Paraffin Scale. This test consists in determining the amount of paraffin present. It is made as a means of identification, and is not a very accurate test; and there is considerable difference of opinion as to its value.

528. THE FLUX. A flux is a heavy oil or the residue from the distillation of petroleum which is mixed with refined asphalt to make it of suitable consistency for use in a sheet asphalt pavement or as a binder for asphaltic macadam or concrete. Fluxes are usually obtained from paraffin, semi-asphaltic, or asphaltic oils; and vary greatly in character with the petroleum from which they are derived. The lower the specific gravity of the flux, the less the amount required to produce an asphalt cement of the desired consistency. Different asphalts require quite different amounts of flux. For example, Bermudez asphalt requires only 7 per cent of a light flux, while Trinidad asphalt requires 20 per cent.

529. Specifications for Flux. The following are the specifications of the American Society of Municipal Improvements, adopted October 14, 1915, for the flux to be used in preparing asphalt for sheet asphalt pavements.

1. The flux must have a penetration greater than 350 with a No. 2 needle at 77° F. under a 50-gram weight applied for one second.

2. It shall have a specific gravity at 77° F. between 0.92 and 1.02.

3. When 20 grams of the flux are heated for 5 hours at 325° F. in a tin box $2\frac{1}{4}$ inches in diameter and three quarters of an inch deep after the manner officially prescribed, the loss shall not exceed 5 per cent by weight; and the residue left after such heating shall flow at 77° F.

4. The flux shall not flash below 350° F. when tested in a closed oil tester.

5. It shall be soluble in carbon tetrachloride to the extent of not less than 99 per cent.

530. ASPHALT CEMENT. Asphalt cement is produced by mixing refined asphalt and a flux. The asphalt should be heated to

325 to 350° F. and the flux to 150 to 200° F. before they are mixed. The mixing is done by blowing air or steam, preferably the latter, through perforated pipes in the bottom of the melting tank. The mixing should be very thorough, and usually requires three or more hours. Care should be taken that the cement is not burned, particularly if the tank is heated over a fire. The cement will harden if kept heated for a long time or if the agitation is kept up unduly long; but the cement can be softened again by adding more flux and mixing further.

531. SPECIFICATIONS FOR ASPHALT CEMENT. Asphalt cement is used for a bituminous surface on water-bound gravel or macadam roads (§ 589) and for binder in bituminous macadam and bituminous-concrete roads (§ 611 and 622); but principally for sheet asphalt pavements (Art. 1 of Chap. XVI), asphaltic concrete (Art. 2 of Chap. XVI), and also for joint filler for brick, stone-block, and wood-block pavements (Chap. XVI, XVII, and XIX, respectively).

Usually separate specifications are drawn for each of the above uses.

532. Whatever the purpose for which the asphalt is to be used, there are two classes of specifications for it, one known as general or open or blanket specifications, and the other as restricted or special or alternate specifications. The former are drawn so as to include all kinds of asphalt whatever their source or origin; and the latter consist of special requirements for each type or asphalt.

Tables 31, 32 and 33, page 278, 280, and 281, show a summary of restricted specifications of asphalt for different uses; and § 543 contains an example of general specifications for asphalt for sheet asphalt pavements.

There is a sharp difference of opinion as to the relative merits of the two classes of specifications. Those who favor restricted specifications claim that there is so much difference between the different kinds of asphalt that it is impossible to make general requirements which will apply to all and at the same time define any quality so as to make it a real test for any particular kind of asphalt. For example, assume that it is desired to permit the use of any of the four asphalts of Table 31, page 278, and that it is stated that the specific gravity shall be from 0.96 to 1.06. The lower limit is too small to fix this quality in some of the asphalts, and the upper limit is too great to fix it for others. Again, if the specifications state that the penetration shall be between 90 and 160, they will permit the use

of any of the four asphalts of Table 31; but the limits are too wide to secure uniformity in any of the cements, and an entirely unsuitable material could be supplied under such specifications.

On the other hand, equally competent asphalt specialists strongly dissent from the above statements; and claim that the different asphalts on the market are so nearly alike in their essential qualities as not to justify separate specifications. They claim that there is no more reason for separate specifications for the different asphalts than for separate specifications for different brands of portland cement. They claim that the bitumen in all asphalts is practically the same, and that the seeming difference in asphalts is due to the mineral matter which they contain. For example, Trinidad refined asphalt (§ 498), one of the best-known and most extensively used of the natural asphalts, contains about 36 per cent of mineral matter; and consequently its specific gravity is greater and its penetration is less than a more pure asphalt. The finely divided mineral matter in this asphalt does not injure it for some uses, for example, sheet asphalt pavements, since in practice a considerable amount of fine mineral matter is added to the asphalt to give it physical stability (§ 826). Those who advocate general specifications claim that the illustration concerning specific gravity in the preceding paragraph is wide of the mark, since a test for specific gravity is valuable only as a means of identifying the material, and in no way aids in determining any essential quality. They also claim that the penetration of the pure bitumen in all asphalts is substantially the same; and that the difference in the limits is only to provide for the difference between heavy and light traffic, a difference in the fineness of the sand, and differences in climatic conditions.

The divergence of opinion as to the merits of the two types of specifications is shown by the fact that the standard specifications of the American Society of Municipal Improvements for bituminous macadam (§ 537–38), bituminous concrete (§ 539–40), and seal coat, (§ 541), adopt the restricted or special form of specifications for the asphalt; while the standard specifications of the same Society for asphalt concrete and sheet asphalt pavements (§ 542–43) are based upon general or blanket specifications for the asphalt. However, a recent vote shows that the weight of the society is in favor of the general specifications.

533. The writing of specifications for asphaltic cement requires thorough laboratory knowledge of the chemical and physical characteristics of asphalt, and also practical experience in the use of the

material.* Great care must be used in changing the limits in specifications, since a change in the value for one element may require a corresponding change in some other factor. Below are specifications for asphaltic cement that have been successfully used for roads and pavements.

534. Asphalt for Bituminous Surface on Water-bound Macadam. The following are the specifications of the Barber Asphalt Company for liquid asphalt for both cold and hot-surface application to water-bound macadam: †

535. *Liquid Asphalt A.* (*For Cold Application.*) 1. Specific Gravity: The specific gravity at 60° F. shall not be less than 0.91.

2. Flash Point: The flash point by the Tagliabue open cup shall not be less than 100° F.

3. Viscosity: The specific viscosity by the Engler apparatus at 77° F., for the first 50 c.c. shall be between 90 and 100.

4. Bitumen Soluble in Disulphide: The bitumen soluble in carbon disulphide shall not be less than 99 per cent.

5. Paraffin Scale: The paraffin scale determined by the Holde method shall not be more than 0.25 per cent.

6. Distillation: When evaporated to 80 per cent by weight, by heating in an open dish at 150° F., the residue shall have at 77° F. with a No. 2 needle under a weight of 50 grams in 1 second, a penetration of not less than 20 mm.; and its adhesiveness by the Osborne test shall not be less than 200 seconds.

536. *Liquid Asphalt B.* (*For Hot Application.*) 1. Specific Gravity: The specific gravity at 60° F. shall be not less than 1.00.

2. Flash Point. The flash point by the Cleveland cup shall be not less than 325° F.

3. Viscosity: The specific viscosity by the Engler apparatus at 212° F., for the first 50 c.c. shall be from 23 to 33.

4. Bitumen Soluble in Disulphide: The bitumen soluble in carbon disulphide shall be not less than 99.0 per cent.

5. Paraffin Scale: The paraffin scale by the Holde method shall not be more than 0.25 per cent.

6. Distillation: The loss at 325° F. after 5 hours of 50 grams in a $2\frac{1}{4}$ by $1\frac{1}{2}$-inch dish shall not be more than 1.0 per cent.

7. Residue, loss by evaporation: The residue of a 5.0 mm. penetration at 77° F. under a load of 100 grams with a No. 2 needle at 5 seconds, when evaporated at 500° F. in an open dish shall lose not less than 75.0 per cent.

8. Adhesiveness: The adhesiveness at 77° F. by the Osborne test shall not be less than 400 seconds.

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* For the methods and results of tests of asphalts see Hubbard's Dust Preventives and Road Binders, 8vo, p. 416, John Wiley & Sons, New York, 1910; Richardson's Modern Asphalt Pavement, 8vo, p. 629, John Wiley & Sons, New York, 1908.

† Letter to the author under date of July 13, 1917.

537. Asphalt Binder for Bituminous Macadam. The American Society of Municipal Improvements on October 12, 1916, adopted restricted specifications for four kinds of asphalt, any one of which is acceptable as a binder for bituminous macadam. The full specifications for an asphalt cement made from Gilsonite and asphaltic oil follow. The specifications for the three other asphalts are in exactly the same form; and Table 31 gives the essential elements of the specifications of all four.

TABLE 31

COMPARISON OF SPECIFICATIONS FOR ASPHALT CEMENTS FOR BITUMINOUS MACADAM

Standards of American Society of Municipal Improvements, Adpoted October 1, 1915

Ref. No.	Items.	Kind of Asphalt Cement.			
		Gilsonite and Asphalt Oil.	Texas and California Oil Asphalt.	Mexican Oil Asphalt.	Bermudez Asphalt.
1	Shall not foam at.....	177° C.	177° C.	177° C.	177° C.
2	Flash point, not less than.....	205° C.	205° C.	205° C.	163° C.
3	Specific gravity at 25° C.....	0.96–1.00	1.00–1.03	1.025–1.045	1.035–1.060
4	Penetration—				
	100 grams, 5 sec., 25° C.....	100–120	90–110	110–130	130–160
	200 grams, 60 sec., 40° C....	>50	>15	>30	>30
5	Melting point by cube method.	>60° C.	>30° C.	>40° C.	
	Viscosity by N. Y. float apparatus.....	.....	.....	.....	120–180 sec.
6	Distillation, loss after 5 hrs.....	<2.0%	<2.0%	<2.0%	<3.0%
7	Bitumen soluble in disulphide..	99.5%	99.5%	99.5%	94–98.0
8	Bitumen soluble in tetrachloride	99.5%	99.5%	99.5%	98.5%
9	Bitumen soluble in naphtha....	75–85%	75–85%	70–80%	75–85%
10	Fixed carbon.....	8–12%	9–13%	12–17%	11–14%

538. *Gilsonite and Asphaltic Oil.* 1. Foam: The asphalt cement shall be homogeneous, free from water, and shall not foam when heated to 177° C. (350° F.)

2. Flash Point: It shall show a flash point of not less than 205° C. (400° F.) when tested in the New York State Board of Health Closed Oil Tester.

3. Specific Gravity: Its specific gravity at a temperature of 25° C. (77° F.) shall be not less than 0.960 nor more than 1.000.

4. Evaporation: When tested with a standard No. 2 needle by means of a standard penetrometer, it shall show penetrations within the following limits for the conditions stated, the penetrations being expressed in hundredths of a centimeter: 100-gram load, 5 seconds at 25° C. (77° F.), from 100 to 120; 200-gram load, 1 minute at 4° C. (39° F.), not less than 50.

5. Melting Point: Its melting point as determined by the cube method shall be not less than 60° C. (140° F.).

6. Distillation: When 50 grams of the material is maintained at a uniform temperature of 163° C. (325° F.) for 5 hours in an open cylindrical tin dish $5\frac{1}{2}$ centimeters (about $2\frac{1}{4}$ inches) in diameter, with vertical sides measuring approximately $3\frac{1}{2}$ centimeters (about $1\frac{1}{2}$ inches) in depth, the loss in weight shall not exceed 2.0 per cent of the original weight of the sample.

Penetration of Residue: The penetration of the residue when tested as described in paragraph 4 with a standard No. 2 needle under a load of 100 grams for 5 seconds at 25° C. (77° F.), shall be not less than one half the penetration of the original material tested under the same condition.

7. Bitumen Soluble in Disulphide: Its bitumen as determined by its solubility in chemically pure carbon disulphide at room temperature, shall be not less than 99.5 per cent.

8. Bitumen Soluble in Tetrachloride: It shall be soluble in chemically pure carbon tetrachloride at room temperature, to the extent of not less than 99.5 per cent of its bitumen as determined by paragraph 7.

9. Bitumen Soluble in Naphtha: It shall be soluble in 86 to 88° Baumé paraffin naphtha, of which at least 85.0 per cent distills between 35° and 65° C. (95° and 149° F.), to the extent of not less than 75.0 per cent nor more than 85.0 per cent of its bitumen as determined by paragraph 7.

10. Fixed Carbon: It shall yield not less than 8.0 per cent nor more than 12.0 per cent of fixed carbon.

539. Asphalt Binder for Bituminous Concrete. The American Society of Municipal Improvements on October 12, 1916, adopted restricted specifications for four kinds of asphalt any one of which is acceptable as a binder for bituminous concrete. The full specifications for asphalt made of Gilsonite and asphaltic oil follow. The specifications for the four other materials are in exactly the same form. Table 32, page 280, gives the essential elements of the specifications of all five asphalts.

540. *Gilsonite and Asphalt Oil.* 1. Foam: The asphalt cement shall be homogeneous, free from water, and shall not foam when heated to 177° C. (350° F.).

2. Flash Point: It shall show a flash point of not less than 205° C. (400° F.)

3. Specific Gravity: Its specific gravity at a temperature of 25° C. (77° F.) shall be not less than 0.970 nor more than 1.000.

4. Penetration: When tested with a standard No. 2 needle by means of a Dow penetrometer (or other penetrometer giving the same results as the Dow machine), it shall show penetrations within the following limits for the conditions stated, the penetrations being expressed in hundredths of a centimeter: 100-gram load, 5 seconds, at 25° C. (77° F.), from 75 to 90; 200-gram load, 1 minute, at 4° C. (39° F.), not less than 35; 50-gram load, 5 seconds, at 46° C. (115° F.) net more than 250.

5. Melting Point: Its melting point as determined by the cube method shall be not less than 55° C. (131° F.).

6. Evaporation: When 50 grams of the material is maintained at a uniform temperature of 163° C. (325° F.) for 5 hours in an open cylindrical tin dish, $5\frac{1}{2}$ centimeters (about $2\frac{1}{4}$ inches) in diameter, with vertical sides measuring approximately $3\frac{1}{2}$ centimeters (about $1\frac{1}{2}$ inches) in depth, the loss in weight shall not exceed 1.0 per cent of the original weight of the sample.

Penetration of Residue: The penetration of the residue, when tested as

described in paragraph 4 with a standard No. 2 needle under a load of 100 grams for 5 seconds at 25° C. (77° F.) shall be not less than one half the penetration of the original material tested under the same conditions.

7. Bitumen Soluble in Disulphide: Its bitumen as determined by its solubility in chemically pure carbon disulphide at room temperature shall not be less than 99.5 per cent.

8. Bitumen Soluble in Tetrachloride: It shall be soluble in chemically pure carbon tetrachloride at room temperature to the extent of not less than 99.5 per cent of its bitumen as determined by paragraph 7.

9. Bitumen Soluble in Naphtha: It shall be soluble in 86 to 88° Baumé paraffin naphtha, at least 85 per cent of which distills between 40 and 55° C. (104° and 131° F.), to the extent of not less than 70.0 per cent nor more than 80.0 per cent of its bitumen as determined by paragraph 7.

10. Fixed Carbon: It shall yield not less than 8.0 per cent nor more than 12.0 per cent of fixed carbon.

TABLE 32

COMPARISON OF SPECIFICATIONS FOR ASPHALT CEMENTS FOR BITUMINOUS CONCRETE

Standards of American Society of Municipal Improvements, Adopted October 14, 1915

Ref. No.	Item.	Kinds of Asphalt.				
		Gilsonite and Asphalt Oil.	Texas Oil Asphalt.	California Oil Asphalt.	Mexican Oil Asphalt.	Bermudez Asphalt.
1	Shall not foam at.....	177° C.	177° C.	177° C.	177° C.	177° C.
2	Flash point, not less than.	205° C.	205° C.	205° C.	205° C.	165° C.
3	Specific gravity at 25° C..	0.97–1.000	1.000–1.030	1.030–1.040	1.025–1.050	1.040–1.060
4	Penetration—100 grs.. ..	75–90	90–100	70–90	85–95	140–160
	—200 grams..	>35	>30	>10	>20	>40
5	Melting point by cube method.....	>55° C.	>50° C.	>45° C.	>50° C.	
	Viscosity by N. Y. float apparatus.....	.....	.....	.....	.....	120–180 sec
6	Evaporation, loss after 5 hrs.....	<1.0%	<1.0%	<2.0%	<2.0%	<3.0%
7	Bitumen soluble in disulphide.....	99.5%	99.5%	99.5%	99.5%	93–98%
8	Bitumen soluble in tetrachloride.....	99.5%	99.5%	99.5%	99.5%	98.5%
9	Bitumen soluble in naphtha.....	70–80%	72–78%	80–88%	67–77%	75–85%
10	Fixed carbon.....	8–12%	11–15%	10–14%	12–18%	11–15%

541. Asphalt for Seal Coat for Bituminous Concrete. The American Society of Municipal Improvements adopted restricted specifications for three kinds of asphalt for the seal coat of bituminous concrete pavements in which tar is the cementing material of the concrete. These specifications are of the same general form as those in § 538 and § 540. The essential elements of the specifications are shown in Table 33.

TABLE 33

SPECIFICATIONS FOR ASPHALT FOR SEAL COAT FOR TAR-CONCRETE PAVEMENTS

Standards of American Society of Municipal Improvements, Adopted October 14, 1915

Ref. No.	Items.	KINDS OF ASPHALT.		
		Gilsonite and Asphalt Oil.	Texas Oil Asphalt.	Mexican Oil Asphalt.
1	Shall not foam at	177° C.	177° C.	177° C.
2	Shall not flash at	205° C.	205° C.	205° C.
3	Specific gravity at 25° C	1.025–1.050	1.030–1.045	1.025–1.055
4	Penetration—100 grams	85–95	60–70	60–70
	200 grams	>20	>18	>16
5	Melting point by cube method	50° C.	60° C	55° C.
6	Distillation, loss after 5 hours	<2.0%	<1.0%	<1.0%
	Penetration of residue, per cent of original	>50%	>50%	>50%
7	Bitumen soluble in disulphide	99.5%	99.5%	99.5%
8	Bitumen soluble in tetrachloride	99.5%	99.5%	99.5 %
9	Bitumen, per cent of total soluble in naphtha	70–80%	70–80%	67–77%
10	Fixed carbon, per cent	8–12	12–16	13–18

542. Asphalt for Sheet Asphalt Pavements. The following are the specifications of the American Society of Municipal Improvements, adopted October 14, 1915, for asphalt cement for sheet asphalt and asphalt concrete pavements:

1. Homogeneous: The asphalt cement shall be thoroughly homogeneous.

2. Penetration: It shall have a penetration at 77° F. of from 30 to 55 for heavy traffic streets, and 55 to 85 for light traffic streets, depending upon the sand and asphalt used and the local climatic conditions.

3. Flash Point: It shall not flash below 350° F. when tested in a closed oil tester.

4. Evaporation: When 20 grams of the asphalt cement are heated for 5 hours at 325° F. in a tin box $2\frac{1}{4}$ inches in diameter and $\frac{3}{4}$ of an inch deep, after the manner officially prescribed, the loss shall not exceed 5 per cent by weight; and the penetration, at 77° F., of the residue left after such heating must not be less than one half the penetration, at 77° F., of the original sample before heating.

5. Ductility: Either the asphalt cement or its pure bitumen when made into a briquette in the Dow mold shall have at 50 penetration at 77° F., a ductility of not less than 30 centimeters, when the two ends of the briquette are pulled apart at the uniform rate of 5 centimeters per minute.

When the asphalt cement as used has a penetration other than 50 at 77° F., an increased ductility of 2 centimeters will be required for every 5 points in penetration above 50; and a corresponding allowance will be made for a penetration below 50.

543. There are two marked differences between the preceding specifications and those for asphalt binder for bituminous macadam (§ 538) and those for asphalt binder for bituminous concrete (§ 540).

In the first place, the preceding specifications are briefer, having only five items while the others have ten; but the longer specifica-

tions contain several items of only minor importance. For example, the foam test determines only the presence of water, but determines nothing concerning the quality of the asphalt. Again, the specific gravity test is of value in identifying the asphalt, but is of no value in determining its quality. Further, the melting point indicates consistency, which is more accurately determined by the penetration test. On the other hand, notice that the specifications of § 542 alone contain a test for ductility, which is the sole test to determine the cementing value of the asphalt.

In the second place, the specifications of § 542 are the general or blanket form, while those of § 538 and § 540 are restricted or special form. For a discussion of the merits of the two forms, see § 532.

544. Asphalt Filler for Block Pavements. It is important that the asphalt used as a filler in block pavements shall be affected as little as possible by temperature changes; and therefore the manufacturers have prepared a material especially for this purpose, partly by refining the asphalt and partly by hardening it by oxidation, i. e., by passing air through it. The following are the usual specifications for an asphalt filler for brick, stone-block, and wood-block pavements.*

The asphalt paving cement shall be obtained by the distillation of an asphaltic petroleum at a temperature not exceeding 700° F., and shall comply with the following requirements:

1. It shall be homogeneous.
2. The melting point shall not be less than 130 nor more than 145° F.
3. The solubility in carbon tetrachloride shall not be less than 98½ per cent.
4. The penetration at 77° F. shall not be less than 60 nor more than 100; and the penetration at 100° F. shall not exceed three times the penetration at 77° F. The contractor before beginning work shall obtain from the engineer a statement in writing as to the penetration desired, and a variation not greater than ten points either way from this penetration will be permitted.
5. The ductility at 77° F. shall not be less than 40 centimeters, the rate of elongation being five centimeters per minute.
6. It shall not lose more than 3 per cent by volatilization when maintained at a temperature of 325° F. for 5 hours; nor shall the penetration of the residue after such heating be less than one half the original penetration.
7. The asphalt filler shall be used on the work at a temperature of not less than 275° F.; and shall at no time be heated above 350° F.
8. It shall be delivered where directed by the engineer in time to allow for examination and analysis.

*Specifications for Stone Block Paving, adopted by American Society of Municipal Improvements, 1916.

545. COST. The cost of all materials is abnormal at present owing to the Great European War; but the asphalt market is further disturbed by the unsettled political conditions in Mexico, which make it difficult to obtain Mexican petroleum for fluxing. The prices of solid refined asphalt for January, 1917, which prices obtained for the year 1917, f.o.b. Maurer, N. J., in tank cars, were about as follows:

KINDS OF ASPHALT.	Price per Ton (2000 Lb.)	Per Cent Bitumen.	Value for 100 Per Cent Bitumen.
Bermudez	$27.00	95.0	$25.65
Mexican	15.00	95.5	14.32
Residual	16.00*		
Texas	18.00	98.8	17.78
Trinidad	19.00	99.5	18.90

* Varies $3.00 to $4.00 either way in different parts of the country. The average price has advanced 100 per cent since 1914.

If asphalt is bought in barrels or drums, the cost is usually 1.5 to 2 cents per gallon more than above, with sometimes a little rebate on the returned barrels.

Liquid asphalt is now (1917) 7 cents per gallon f.o.b. Maurer, N. J.

546. For current prices of asphalts, consult the price lists in the technical journals.

ART. 2. PETROLEUM

547. CLASSIFICATION. There are two types of crude petroleum—one giving a paraffin residue, and the other an asphalt residue. The petroleums from Pennsylvania, Ohio, Indiana and Illinois have a paraffin residue or base; while those from California and Mexico and some from Texas have an asphaltic base. The oils from Kentucky, Louisiana, and some from Texas have a mixed paraffin and asphalt base, and are usually called semi-asphaltic oils.

The oils having a paraffin base are more or less greasy, and have no binding qualities, but rather a lubricating effect; and are useful only as a temporary dust layer. The oils having an asphaltic or bituminous base are more valuable for roads, since the bituminous base binds the particles of the road together, even after the more volatile portions of the oil have evaporated.

Crude petroleum as it comes from the well is an oily liquid, varying in color from greenish brown to nearly black, and varying in specific gravity from 0.73 to 0.97. In the refining process the more

volatile and more valuable constituents, as benzine, gasoline, kerosene, and lubricating oils, are driven off by heat. It is the residue that is used in oiling roads and as a flux for softening the solid native asphalts (§ 528–29). The character of the residue varies with the crude petroleum and with the process of refining, and its value for road purposes depends upon its specific gravity and the amount of bitumen it contains.

548. Methods of Refining. There are two methods of refining petroleum to produce materials for use on roads. One method is that of ordinary distillation by the use of external heat, usually steam. The distillation is carried on until only the solid or semi-solid portion remains. This method is not usually applied to paraffin petroleums on account of the high temperatures necessary and the resulting decomposition.

The second method consists in blowing atmospheric air through petroleum heated to a temperature below that required for distillation. The air produces oxidation and condensation of the lighter hydrocarbons, and the oil gradually thickens. This method is usually applied to oils having a paraffin base; and the residue is known as blown oil, or sometimes as blown-oil asphalt, although it is usually paraffin or at most a semi-asphalt mixture.

549. Shipping the Oil. Road oil is usually shipped in tank cars holding either 4000 to 6000 gallons or 8000 to 10,000 gallons, the latter being much more common. Oil may be had in barrels; but it is then more expensive, and is also much more difficult to handle. The tank cars are equipped with steam heating coils, so the material may be heated in the tank by attaching a steam pipe or hose.

There are a number of simple pumps on the market that will pump either hot or cold oil. The ordinary thresher's water-tank pump may be used for pumping cold oil; but not hot oil, as it will soon burn out the valves. Fig. 92, page 285, shows the method of pumping road oil from the dome of a tank car by means of a hand diaphragm pump; and a thresher's water-tank pump may be used in the same way. However, this method is nearly obsolete, since state and county highway departments usually own outfits made particularly for this purpose.

Power-driven diaphragm and rotary pumps are the forms generally used; and are attached to the outlet in the bottom of the tank car. These pumps are driven by an independent gasoline engine or by steam from a steam road-roller, which is sometimes needed at the tank car to supply steam to heat the oil. Fig. 93 shows the method

of transferring road oil from the tank car to the distributing wagon by means of a gasoline-driven rotary pump.

550. Asphaltic Content of Road Oils. Road oils are frequently referred to as containing a certain per cent of asphalt; and the oil refineries always classify road oils according to their asphaltic content—see § 561.

This " asphalt " is not a definite compound that can be determined by chemical analysis. To determine the " asphalt " in a road oil, the oil is heated in a closed oven to a temperature of 400° F., which drives off the light or volatile constituents and leaves a semi-

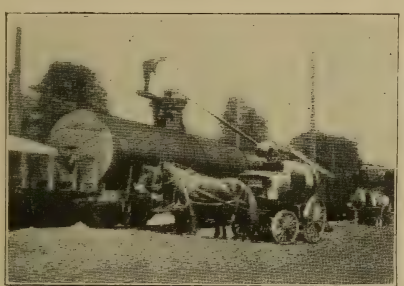

Fig. 92.—Unloading Oil with Diaphragm Pump.

Fig. 93.—Unloading Oil with Rotary Pump.

solid or solid residue. This residue is called asphalt, although it may contain many different bitumens. If the residue is paraffin, it is useful as a dust layer, but worthless as a road binder. Since road oil is so cheap, it is not likely that the residue contains any adulteration. The amount of residue in a road oil gives no indication of its value for use on a road, since the residue may be wholly paraffin, or semi-asphalt, or asphalt. However, the per cent of " asphalt " does give some indication as to the viscosity of the oil, i. e., as to the amount of body it contains. The method employed and equipment used in determining the amount of " asphalt " vary considerably, and are not usually stated; hence the result is quite indefinite. No reliance should be placed upon such a loose term; but the oil should be bought to conform to definite specifications.

The degree of hardness of this residue is measured by the depth of penetration of a No. 2 needle under a load of 100 grams in 5 seconds. It is sometimes specified that the road oil shall contain a certain per cent of " asphalt " having a stated penetration. For example: " The oil shall contain 90 per cent of ' asphalt ' having a penetration of 80."

551. Specifications for Road Oil. Road oils are usually bought without any specifications as to their composition and also without inspection or analysis. This is very unfortunate, since the residue may be paraffin, which is a lubricant rather than a binder; and also since the residue, even though a bitumen, may have been burned in the refining process until it possesses little or no binding qualities.

Specifications differ considerably according to the purpose for which the oil is to be used or the conditions under which it is applied; and practice has not yet established a standard for any particular purpose or condition. Below are the specifications of several grades of road oil that have been successfully used.

552. For Park Drives. The following are the specifications of the light oil used as a dust layer (§ 330), in Washington, D. C., on gravel park drives.*

1. The oil shall be a viscous fluid product, free from water, and showing some degree of adhesiveness when rubbed between the fingers.

2. It shall have a specific gravity of not less than 0.940 at 25° C.

3. It shall be soluble in carbon disulphide at air temperature to at least 99 per cent; and shall not contain over 0.2 per cent of insoluble inorganic matter.

4. It shall contain not less than 3 per cent nor more than 10 per cent of bitumen insoluble in 86° paraffin naphtha at air temperature.

5. When 240° c.c. of the oil is heated in an Engler viscosimeter to 50° C. and maintained at this temperature for at least 3 minutes, the first 50 c.c. shall flow through the aperture in not less than 10 minutes nor more than 20 minutes.

6. When 20 grams of the material is heated for 5 hours in a cylindrical tin dish, approximately $2\frac{1}{2}$ inches in diameter by 1 inch high, at a constant temperature of 163° C., the loss in weight by volatilization shall not exceed 20 per cent. The residue should be decidedly sticky.

7. Its fixed carbon shall not be less than 3.5 per cent.

553. For Earth Roads. The two following specifications have been adopted by the Illinois Highway Department,† and have practically been adopted by nearly all State Highway Departments for the surface treatment of earth roads. The oils are to be tested according to the method described in Bulletin No. 314, U. S. Department of Agriculture, December 10, 1915.

554. *For Loam and Clay.* The following light oil should be applied cold, for a first application on loam or clay. For subsequent applications use the oil as described in the next section.

* Paper by Col. Spencer Cosby, U. S. Army, in charge of Buildings and Grounds, Washington, D. C., presented before Section D of the American Association for Advancement of Science, December 29, 1911.

† Private letter from W. W. Marr, Chief Highway Engineer, under date of July 18, 1917.

1. The oil shall be homogeneous and free from water.
2. Specific Gravity 25° C. (77° F.) ..... not less than 0.890
3. Bitumen soluble in disulphide ..... not less than 09.5%
4. Residue of 100 penetration * ..... 40 to 60%
5. Specific viscosity at 40° C. (104° F.) ..... 10.0 to 25.0

When it is desired to apply the oil hot, oils somewhat more viscous and having a specific viscosity at 40° C. (104° F.) up to 50 will be acceptable, provided these oils conform to the requirements of the specifications in all other respects. An oil having a specific viscosity at 40° C. (104° F.) of more than 25.0 will not be accepted, unless it is to be applied hot.

555. *For Sandy Soil.* The following oil should be applied cold, and is suitable for a dust layer on a sandy earth road, for a second application on a loam or clay road, and also for a surface application on a water-bound gravel or macadam road.

1. The oil shall be homogeneous and free from water.
2. Specific gravity at 25° C. (77° F.) ..... not less than 0.910
3. Specific viscosity at 40° C. (104° F.) ..... 10.0 to 25.0
4. Loss at 163° C. (325° F.) for 5 hours ..... not over 25%
5. Bitumen soluble in disulphide ..... not less than 99.5%
6. Bitumen insoluble in 86° B. naphtha ..... not less than 5%
7. Fixed carbon ..... not less than 4.0%
8. Specific viscosity at 40° C. (104° F.) ..... 10.0 to 25.0

When it is desired to apply the oil hot, oils somewhat more viscous and having a specific viscosity of 40° C. (104° F.) up to 50 will be acceptable, provided these oils conform to the requirements of the specifications in all other respects. An oil having a specific viscosity at 40° C. (104° F.) of more than 25.0 will not be accepted unless it is to be applied hot.

556. For Water-bound Gravel or Macadam. The three following specifications have been adopted by the Illinois Highway Department † for a dust layer and a protective coating on water-bound gravel or macadam roads, and practically the same have been adopted by most of the State Highway Departments. The oils are to be tested according to the methods described in Bulletin No. 314, U. S. Department of Agriculture, December 10, 1915.

The light oil (§ 557) is preferable for the first application or where the road is somewhat dusty, since it penetrates better than the heavier oils; but for subsequent applications a heavier oil (§ 558 or § 559) is preferable. If the gravel or macadam is very clean, the heavier oil may be used for a first application.

* Am. Soc. Test. Mat. Standard Test, D–5–16.

† Private letter from W. W. Marr, Chief Highway Engineer, under date of July 18, 1917.

557. *Light Oil.* The following oil is to be applied cold.

1. The oil shall be homogeneous and free from water.
2. Specific gravity 25° C. (77° F.).....0.920 to 0.970
3. Loss at 163° C. (325° F.) for 5 hours.....20.0% to 30.0%
4. Bitumen soluble in disulphide.....not less than 99.5%
5. Bitumen insoluble in 86° B. naphtha.....5.0 to 20.0%
6. Fixed carbon.....4.0% to 10.0%
7. Specific viscosity at 25° C. (77° F.).....30.0 to 70.0

558. *Medium Oil.* The following oil need not be applied hot except when the temperature of the air is below 80° F.

1. The oil shall be homogeneous, free from water, and shall not foam when heated to 100° C. (212° F.).
2. Specific gravity 25° C. (77° F.....0.960 to 1.010
3. Flash point.....not less than 100° C. (212° F.)
4. Float test at 32° C. (90° F.).....30 to 90 seconds
5. Loss at 163° C. (325° F.) for 5 hours.....not over 15.0%
6. Float test of residue at 50° C. (122° F.).....90 to 180 seconds
7. Bitumen soluble in disulphide.....not less than 99.5%
8. Bitumen insoluble in 86° B. naphtha.....7.0 to 20.0%
9. Fixed carbon.....5.0% to 10.0%
10. Specific viscosity at 100° C. (212° F.).....5.0 to 15.0

559. *Heavy Oil.* The following oil should be applied hot.

1. The oil shall be homogeneous, free from water, and shall not foam when heated to 150° C. (302° F.)
2. Specific gravity 25° C. (77° F.).....not less than 0.980
3. Flash point.....not less than 150° C. (302° F.)
4. Float test at 50° C. (122° F.).....100 to 200 seconds
5. Loss at 163° C. (325° F.) for 5 hours,.....not over 5.0%
6. Float test of residue at 50° C. (122° F.).....120 to 240 seconds
7. Bitumen soluble in disulphide.....not less than 99.5%
8. Bitumen insoluble in 86° B. naphtha.....10.0 to 25.0%
9. Fixed carbon.....7.0% to 15.0%
10. Specific viscosity at 100° C. (212° F.).....30.0 to 70.0

560. Cost. The price of road oils varies greatly, partly because of the natural variation with locality, but chiefly because a large proportion of road oils is sold without specifications or inspection. The demand for oil for road purposes has increased so rapidly in recent years that the price has advanced more rapidly than most construction materials.

561. The following are the market quotations in *Engineering News-Record*, July 5, 1917. The prices are for road oil in tank cars (8000 gallons minimum capacity) f.o.b. places named.

New York City,	40–50 per cent asphalt	$6\frac{1}{2}$ cts. per gal.
	60–70 per cent asphalt	7 cts. per gal.
	dust layer	$7\frac{1}{4}$ cts. per gal.
	binder	$8\frac{1}{2}$ cts. per gal.
St. Louis,	asphalt	5 cts. per gal.
Dallas,	40–50 per cent asphalt	6 cts. per gal.
	60–70 per cent asphalt	$7\frac{1}{2}$ cts. per gal.
San Francisco,	75–79 per cent asphalt (barrel = 42 gal.)	$1.83 per bbl.

ART. 3. TAR

563. The tar used in road work is obtained as a by-product in the destructive distillation of bituminous coal in the manufacture of illuminating gas or in the production of coke, as well as in the decomposition of petroleum.

564. DEFINITIONS. *Coal Tar.* Tar produced from the destructive distillation of coal.

Coke-oven Tar. A by-product in the manufacture of coke.

Gas-house Tar. A by-product in the manufacture of illuminating gas from coal.

Oil-gas Tar. A by-product in the manufacture of illuminating gas from petroleum.

Pitch. The solid residue produced by the evaporation or distillation of tar.

Refined Tar. A tar freed from water by evaporation or distillation, which process is continued until the tar is of the desired consistency. When all the water is driven off, it is called *Dehydrated Tar.* Refined tar is also produced by fluxing the tar residuum with a tar distillate, in which case the product is called *Cut-back Tar.*

Water-gas Tar. A by-product in the manufacture of carbureted water-gas from petroleum.

565. CHARACTERISTICS OF TAR. Most of the tar used in road work is coal tar, either coke-oven or gas-house tar. In some particulars the characteristics of tars overlap; but the following table shows their chief differences:

CHARACTERISTICS.	KIND OF TAR:	
	COKE-OVEN.	GAS-HOUSE.
Water, per cent	2.2	2.9
Light oil up to 200° C	3.4	4.0
Creosote oil, per cent	14.5	8.6
Naphthalene, crude, per cent	6.7	7.4
Anthracene, crude, per cent	27.3	17.4
Pitch, per cent	44.3	58.4
Free carbon, per cent	5–8	15–25

The quality of gas-house tar depends upon the temperature at which the distillation takes place. The distillation usually takes place at a high temperature; and consequently the tar contains less of the heavy oils and more of the solid bitumen and more free carbon, and is not desirable for road work, because of an excess of free carbon and of the lack of the heavy oils.

Coke-oven tar is usually formed at a lower temperature, and hence contains more of the heavy oils and less free carbon; and is therefore usually more suitable for road work than gas-house tar.

Water-gas tar is lighter than coal tar, contains a larger percentage of heavy oils, and a less percentage of pitch. It is usually low in free carbon, and does not contain ammonia. Since water-gas tars contain comparatively small proportions of pitch, they are not as suitable for a road binder as coal-gas or coke-oven tars; but since they contain a larger percentage of the heavier oils, they are desirable materials for use as dust layers.

566. Crude tar is refined by driving off the lighter oils. The residue may be liquid or solid according to the temperature to which the distillation was carried and the extent to which the heavy oils have been removed. Sometimes the distillation is carried only far enough to drive off the water and the lighter oils. Such a product is known as dehydrated tar; and it is more suitable for road work than crude tar, since it contains no water or ammonia.

567. Shipping Tar. Tar is shipped in barrels or metal drums or in tank cars; and is unloaded and distributed the same as asphalt and oil—see § 504 and § 549.

568. Specifications for Tar. Practice has not established standard specifications; and consequently there are a great number in use, which differ according to the source or character of the tar and also according to the opinion of the one writing the specifications. Only an expert road engineer and chemist should attempt to prepare specifications; and then great care is necessary, since a limitation in one particular may affect the limits of some other factor. The producers of bituminous materials make a variety of grades of material, which are sold under different trade names (see § 578).

Below are the specifications for materials that have been successfully used for different kinds of work by good authorities.

569. For Bituminous Surfaces. The two following specifications have been adopted for refined tar for bituminous surfaces on water-bound gravel or macadam roads (Chapter IX), and on bituminous

bound roads (Chapter X) by the Illinois Highway Department,* and are practically the same as those adopted by most State Highway Departments. The tests are to be made as described in Bulletin 314, U. S. Department of Agriculture, December 10, 1915.

For the first treatment of a road the light tar of § 570 is to be preferred; and for subsequent application the heavier tar of § 571 is better.

570. *Hot Application.* The following tar should be applied hot.

1. The tar shall be homogeneous and free from water.
2. Specific gravity 25° C. (77° F.).....1.120 to 1.200
3. Specific viscosity at 40° C. (104° F.).....4.0 to 12.0
4. Total distillate by weight:†
   to 170° C. (338° F.).....not over 5.0%
   to 300° C. (572° F.).....not over 35.0%
5. Specific gravity of total distillate 25° C. (77° F.).....not less than 1.010
6. Melting point of residue.....not over 65° C. (149° F.)
7. Bitumen soluble in disulphide.....88.0 to 96.0%
8. Inorganic matter (ash).....not over 0.5%

571. *Cold Application.* The following tar should be applied cold.

1. The tar shall be homogeneous and free from water.
2. Specific gravity 25° C. (77° F.).....1.180 to 1.250
3. Float test 32° C. (90° F.).....90 to 150 seconds
4. Total distillate by weight:† to 180° C. (338° F.).....not over 1.0%
   to 300° C. (572° F.).....not over 25.0%
5. Specific gravity of total distillate, 25° C. (77° F.).....not less than 1.030
6. Melting point of residue.....not over 75° C. (167° F.)
7. Bitumen soluble in disulphide.....78.0 to 88.0%
8. Inorganic matter (ash).....not over 0.5%

572. For Bituminous Macadam. The American Society of Municipal Improvements on October 12, 1916, adopted standard specifications for two grades of tar for bituminous macadam roads (Art. 1, Chapter X), which materials are optional with each other and also with any of the four kinds of asphalt described in § 537–38 and Table 31, page 278. The specifications in full for water-gas tar are given in § 573; and Table 34 shows the essential features of both tars.

* Private letter from W. W. Marr, Chief Highway Engineer, under date of July 18, 1917.
† Amer. Soc. Test. Mat. Standard Test, D–20–16.

573. *Water-gas Tar.** 1. Foam: Refined water-gas tar shall be homogeneous, free from water, and shall not foam when heated to 121° C. (250° F.).

2. Specific Gravity: The specific gravity at a temperature of 25° C. (77° F.) shall be not less than 1.150 nor more than 1.200.

3. Viscosity: When tested by means of the New York Testing Laboratory Float Apparatus, the float shall not sink in water maintained at 50° C. (122° F.) in less than 120 nor more than 150 seconds.

4. Bitumen Soluble in Disulphide: The bitumen as determined by its solubility in chemically pure carbon disulphide at room temperature, shall be not less than 95.0 per cent; and the material insoluble in carbon disulphide shall not show more than 0.2 per cent ash upon ignition.

5. Distillation: When distilled according to the tentative method recommended by Committee D–4 of the American Society for Testing Materials in 1911, it shall yield not more than 0.5 per cent distillate at a temperature lower than 170° C. (338° F.); not more than 12.0 per cent shall distill below 270° C. (518° F.); and not more than 25.0 per cent shall distill below 300° C. (572° F.).

6. Distillate, specific gravity of: The total distillate from the test made in accordance with paragraph 5 shall have a specific gravity at a temperature of 25° C. (77° F.) of not less than 0.980 nor more than 1.020.

7. Distillate, melting point of: The melting point, as determined in water by the cube method, of the pitch residue remaining after distillation to 300° C. (572° F.) in accordance with the test described in paragraph 5, shall be not more than 75° C. (167° F.)

TABLE 34

COMPARISON OF SPECIFICATIONS FOR TARS FOR BITUMINOUS MACADAM

Standards of American Society of Municipal Improvements, Adopted October 12, 1916

Ref. No.	Items.	Water-gas Tar.	Coal Tar.
1	Shall not foam at	121° C.	121° C.
2	Specific gravity at 25° C	1.150–1.200	1.180–1.300
3	Viscosity by N. Y. float apparatus	120–150 sec.	150–180 sec.
4	Bitumen soluble in disulphide, not less than	95.0%	80.0–95.0
5	Distillation, yield to 170° C., not more than	0.5%	0.5%
	Distillation, yield to 270° C., not more than	12.0%	10.0%
	Distillation, yield to 300° C., not more than	25.0%	20.0%
6	Distillate, total, specific gravity of	0.98–1.020	1.020
7	Residue, melting point of, not more than	75° C.	75° C.

574. For Bituminous Concrete. The American Society of Municipal Improvements on October 12, 1916, adopted standard specifications for two grades of tar suitable for the binder of bituminous concrete (see Art. 2 of Chapter X), which materials are optional to each other and also with any one of the five grades of asphalt

* Specifications for Broken Roads with Bituminous Surface, adopted by American Society of Municipal Improvements, October 12, 1916, p. 24–25.

described in § 540, and Table 32, page 280. The specification in full for one of the tars is given in § 575; and the essential features of both are shown in Table 35.

575. *Water-gas Tar.* 1. Foam: The refined tar shall be homogeneous, free from water, and shall not foam when heated to 150° C. (302° F.).

2. Specific Gravity: Its specific gravity at a temperature of 25° C. (77° F.) shall not be less than 1.160 nor more than 1.200.

3. Viscosity: When tested by means of the New York Testing Laboratory Float Apparatus, the float shall not sink in water maintained at 50° C. (122° F.) in less than 140 seconds nor more than 170 seconds.

4. Bitumen Soluble in Disulphide: The bitumen as determined by its solubility in chemically pure carbon disulphide at room temperature shall be not less than 95.0 per cent; and the material insoluble in carbon disulphide shall show nor more than 0.2 per cent ash upon ignition.

5. Distillation: When distilled according to the tentative method recommended by Committee D–4 of the American Society for Testing Materials in 1911, it shall yield no distillate at a temperature lower than 170° C. (338° F.); not more than 7.0 per cent by weight shall distill below 270° C. (518° F.); and not more than 20.0 per cent by weight shall distill below 300° C. (572° F.).

6. Distillate, specific gravity of: The total distillate from the test made in accordance with paragraph 5 shall have a specific gravity at a temperature of 25° C. (77° F.) of not less than 1.000 nor more than 1.020.

7. Distillate, melting point of: The melting point, as determined in water by the cube method, of the pitch residue remaining after distillation to 300° C. (572° F.), in accordance with the test described in paragraph 5, shall be not more than 75° C. (167° F.).

TABLE 35

COMPARISON OF SPECIFICATIONS FOR TARS FOR BITUMINOUS CONCRETE

Standards of American Society of Municipal Improvements, October 14, 1916

Ref. No.	Items.	Water-gas Tar.	Coal Tar.
1	Shall not foam at	150° C.	150° C.
2	Specific gravity at 25° C	1.160–1.200	1.200–1.300
3	Viscosity by N. Y. float apparatus	140–170 sec.	140–170 sec.
4	Bitumen soluble in disulphide, not less than	95.0%	75.0–90.0%
5	Distillation, yield to 170° C., not more than	0.0	0.0
	" " 270° C., not more than	7.0%	10.0%
	" " 300° C., not more than	20.0%	20.0%
6	Distillate, total, specific gravity of	1.00–1.020	1.030
7	Distillate, residue, melting point of, not more than	75° C.	75° C.

576. For Joint Filler of Block Pavements.* The following are the specifications for a tar suitable for the joint filler of brick, stone-

* P. P. Sharples, Manager and Chief Chemist, Tarvia Department, Barrett Manufacturing Co., forwarded for this use under date of July 13, 1917.

block, or wood-block pavements. The specifications may need a slight variation for the extremes of northern or southern portions of this country.

577. 1. Pitch. The pitch shall be straight-run residue from the distillation of coal tar.

2. Specific Gravity: The specific gravity at 78° F. shall not be less than 1.24 nor more than 1.32.

3. Melting Point: The melting point shall not be lower than 115° F. nor higher than 150° F. For mastic filler the melting point shall be 115 to 135° F.; for brick and stone-block 125 to 140° F.; and for wood-block, 140 to 150° F. The contractor before beginning work on any contract shall obtain from the Chief Engineer in writing a statement as to the melting point desired for that particular contract, and a variation of 5° F. either way from this value will be permitted; but the melting point must be within the limits indicated above.

The melting point should be higher, the steeper the grade. For grades above 10 per cent, in a warm climate, the melting point should be 140° to 150° F.

4. Free Carbon: The free carbon shall not be less than 22 per cent nor more than 37 per cent.

5. Distillation: The specific gravity of the distillate to 670° F. shall be not less than 1.07 at 140° F. compared with water at the same temperature.

578. Trade Names. A trade name is in a sense a specification for a material; and hence the following definitions of well-known trade names for tar products are appropriate here:

Tarvia A. A refined coal tar for hot surface application to macadam roads for preserving them and laying dust. Tarvia A in distinction from Tarvia B forms a perceptible blanket on the surface; and is therefore limited for successful use to roads receiving either wholly automobile traffic or a high percentage of such traffic. It has been largely used in park work in the neighborhood of large cities.

Tarvia B. A refined coal tar for cold surface application as a dust layer and road preservative. Primarily for use on macadam roads, but also applicable to gravel and other hard-surfaced roads.

Tarvia KP. A refined coal-tar binder cut back to permit its use cold in making patches and in other maintenance work on bituminous surfaced and bituminous bound roads.

Tarvia MF. A refined coal tar prepared for use as a mastic with sand in filling the joints of brick, stone-block, and lug wood-block pavements.

Tarvia X. A refined coal tar prepared for use as a binder for bituminous macadam roads. Modifications are made to permit its use in bituminous concrete.

Tarvia XC. A Tarvia X prepared for use in patching and maintaining the joints in concrete roads.

579. Cost of Road Tar. Cost data are always difficult to handle in printed matter, since the record is liable to be out of date

before it is presented to the public; and this seems to be specially true of tar, particularly at the time this paragraph is written.

The cost of road tars meeting the preceding specification, in the Middle and Eastern States where the conditions are more uniform than in other parts of the country, range from 8 to 13 cents per gallon f.o.b. siding at destination. The lighter materials suitable for cold application cost 1 or 2 cents per gallon less than those applied hot.

580. For more recent data consult the price reports in the current technical journals.

CHAPTER IX

BITUMINOUS SURFACES FOR ROADS

582. Before the advent of motor-driven vehicles gravel and macadam roads gave good service; but the coming of the automobile introduced new conditions that made necessary a radical change in the construction of a gravel or macadam road having any considerable proportion of motor-driven traffic. The low-hung swift-moving automobile, more than horse-drawn vehicles, throws the stone dust into the air and thus permits it to be blown away, and besides the rubber tires, unlike steel tires and horse shoes, do not make any stone dust to replace that blown away. Therefore gravel and macadam roads rapidly deteriorate under any considerable motor-driven traffic. This state of affairs led to the introduction, in substantially the past ten years, of several new forms of road construction in which the binding power of clay or stone dust is replaced by that of a bituminous material like tar.

There are two general types of such construction, viz.: one in which a superficial coating of bituminous material is laid upon a gravel, macadam or concrete road, or even upon a brick or stone-block pavement; and the other in which the bituminous material is employed as a binder for the upper stratum of the road. The superficial layer is called a Protective Coating or a Bituminous Carpet, according to its thickness and construction. This type of construction will be considered in this chapter.

When the second form of construction is employed the road is known as either a Bituminous-Macadam or a Bituminous-Concrete Road, according to the details of the construction, which types of construction will be considered in the next chapter.

583. Kinds of Bituminous Surfaces. The bituminous surface may consist either of a thin bituminous film or of a comparatively thick mat composed of successive layers of bituminous

material and screenings, sand or gravel. The former is usually called a Protective Coating, and the latter a Bituminous Carpet.

ART. 1. PROTECTIVE COATING

584. A light oil is sometimes applied to an earth road, a gravel road, or a water-bound macadam road to lay the dust. It is not expected that the oil will have any binding power; and frequent applications are necessary for effectiveness. But when a water-bound gravel or macadam road is required to carry only a small proportion of motor-driven traffic, it is sometimes possible to protect the surface with a thin bituminous coating which will resist the action of both the horse-drawn and motor-driven traffic, and thus prolong the life of the road surface.

585. THE BITUMINOUS MATERIAL. The bituminous material should be fluid at ordinary temperatures in order that it may be applied cold and spread uniformly. It should contain a small amount of volatile oils which will evaporate and leave a cementitious film on the surface. A light refined tar which is fluid at ordinary temperatures (§ 571–72) is generally used. An asphaltic oil containing from 40 to 50 per cent of asphalt gives fair results. Oils are cheap and readily applied; but are not entirely satisfactory for bituminous coatings for the following reasons: 1. Most petroleum products, even those having an asphaltic base, while in a fluid state act to a certain extent as a lubricant. 2. Both medium and heavy asphaltic oils require considerable time to set up; and therefore, if the road is opened to travel before the oil has set, more or less movement of the coating will take place, and it will become wavy and full of bumps.

The amount of tar or asphaltic oil should rarely exceed 0.2 of a gallon per square yard, and an excessive amount is specially to be avoided.

586. The field for this form of surface is comparatively limited, and the effect of such a coating is only temporary; but this treatment is often a valuable means of carrying an old gravel or macadam road along until a better form of treatment can be given. It is more expensive and more permanent than an oil dust-layer (§ 329–31); but is cheaper and less permanent than a bituminous carpet (§ 588).

Art. 2. Bituminous Carpet

588. When the proportion of motor-driven traffic on a water-bound gravel or macadam road becomes considerable (see Table 26, page 177), it is more economical to protect the road surface with a bituminous carpet or blanket than continually to add screenings or gravel to supply binding material. In some cases the mat or carpet is added to prevent the road from being denuded of binder, and in other cases the carpet protects the stone itself from excessive wear, which is particularly important on a road built of soft limestone. The bituminous carpet not only protects the road but eliminates practically all dust.

In consideration of the large mileage of water-bound gravel and macadam roads built before the advent of the automobile, this method of treating such roads is very important. Under some conditions it is still economical to build new water-bound gravel and macadam roads, and cover them with a bituminous carpet; although owing to the difficulties of maintaining a bituminous carpet, it is usually wiser to build a bituminous-macadam or a bituminous-concrete road.

589. The Bituminous Material. Either refined tar (§ 568) or asphaltic oil (§ 551) may be used. The particular grade of tar or oil to be used depends upon the condition of the road and the amount and character of the travel. If the road has begun to ravel and most of the stones have been swept bare of binding material, a refined tar like that in § 571, or a heavy oil like that in § 559 should be used. If some bonding material remains on the road surface and the large stones are not entirely exposed, a medium oil like that in § 558 would be better. If the surface is tightly bound and hard to sweep free from dust and fine material, a tar product like that of § 570 or a light oil like that of § 557 should be selected.

590. Cleaning Road Surface. The road should be swept with a revolving power-broom and then with a hand-broom until the surface is entirely free from dust and fine particles. The bituminous material adheres better if the road is sprinkled before treatment, but it should be allowed to dry before the bituminous material is applied. Unquestionably water on the road when the bituminous material is applied is harmful; but the sprinkling washes off the dust and therefore is beneficial, provided the road is dry when the bituminous material is applied.

Fig. 94 shows the method of cleaning an old macadam road preparatory to applying the bituminous surface.

FIG. 94.—SWEEPING AN OLD MACADAM ROAD BEFORE APPLYING THE BITUMINOUS SURFACE.

591. APPLYING BITUMINOUS MATERIAL. The binder may be applied either by hand or by machine. In the hand method, ordinary garden watering pots or special pouring cans are used, being filled from a large supply tank that is driven along beside the work. It is very difficult to apply the bituminous material evenly with a hand pouring can; and it is necessary immediately to follow the application with a brush broom and sweep the surplus oil ahead. This method of applying the material is very slow and expensive, and is now seldom used except for small jobs and for patch work.

There are many different types of machines for distributing the bituminous material, but in outward appearance they do not differ greatly from the oil distributor shown in Fig. 39 and 40, page 137.

There are a number of hand-drawn cart gravity-distributors. Some horse-drawn distributors have gravity feed; but the mechanical feed or pressure distributor is the more common, since it secures a more uniform distribution and permits more accurate regulation of the amount applied. Some of the distributors have their own heating device; but some are made for spreading cold oil, or depend upon an auxiliary heater. Some distributors deliver the bituminous material in small streams, and others in a fan-like sheet, while still others deliver it in a fine spray. It is claimed that the spray applies the material more uniformly, and that it strikes the surface of the road with enough force to penetrate all interstices and to blow

away all dust, and thus secures a good union with the stone of the road.

Fig. 95 shows a distributing tank which is drawn with horses or behind a road roller. The special features of this distributor are: (1) the bituminous material is heated by steam from a road roller, and hence can not be burned; (2) the material is discharged by air pressure in the tank, and hence there are no pumps to become clogged; and (3) the first cost of the machine is low.

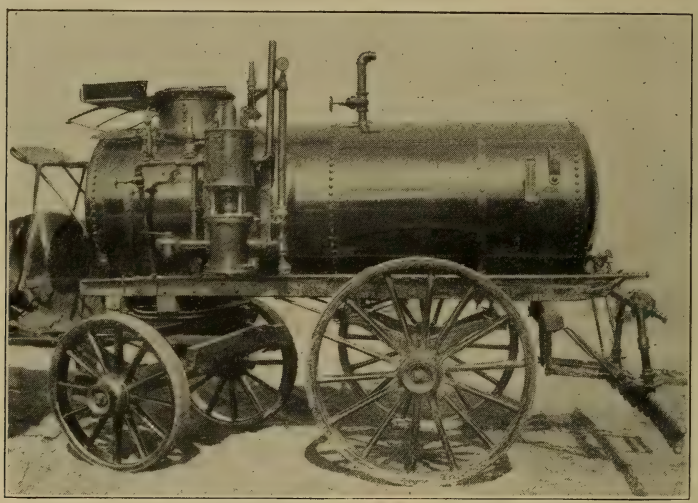

FIG. 95.—HORSE-DRAWN PRESSURE DISTRIBUTOR.

The same features are embodied in a self-contained automobile-truck distributor, which permits work at a greater distance from the central heating plant.

Fig. 96 shows a motor-driven distributor. The distributing head is in three sections, either outside one of which may be turned up and put out of use. With both arms in use the total spread is 16 feet. Fig. 97 shows a spray in use making a patch. Views 1 and 5, Fig. 100, page 311, show a distributor spraying tar.

592. The bituminous material may be delivered in railroad tank-cars or in barrels or metal drums. The first method is objectionable owing to the difficulty of having enough road surface ready to receive 8,000 to 10,000 gallons of tar. When the binder is delivered in barrels or drums, it is heated in a large kettle while the tank wagon is distributing a load.

The heating should be done so as to heat evenly the entire mass, and the heating should be under positive control at all times. The tar should be heated to 93° C. (200° F.) and not above 121° C.

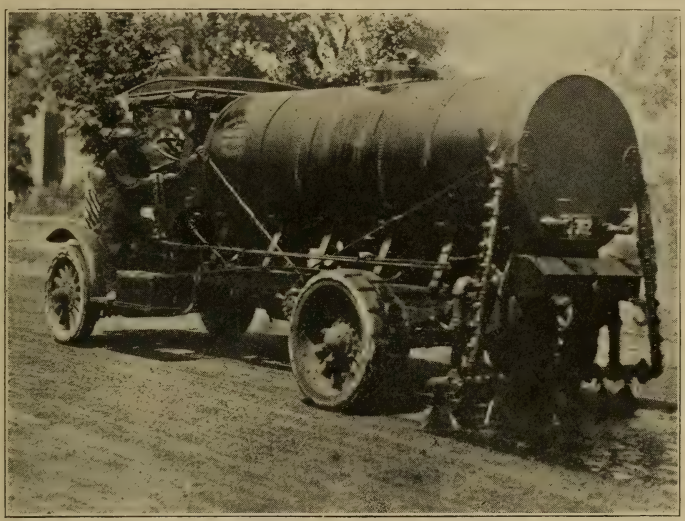

FIG. 96.—AUTOMOBILE PRESSURE DISTRIBUTOR.

(250° F.). Any material heated beyond 121° C. should not be used. The distributing wagon should be supplied with one or more ther-

FIG. 97.—SPRAYING DISTRIBUTOR MAKING A PATCH.

mometers to insure that the temperature of the tar when applied is between the above limits. It is unwise to apply tar when the air or road is below 50° F. (10° C.).

593. The bituminous material is applied at the rate of $\frac{1}{4}$ to $\frac{1}{2}$ gallon per square yard, in either one or two treatments. The carpet should be uniform in thickness, as otherwise the thin places will cut

through, and the thick portions will bunch if soft, and crack if a hard material is used. The thinner the carpet that can carry the traffic the better.

594. After the bituminous material has had a few hours to penetrate the surface of the road, and after it has set up a little, stone screenings or pea gravel is added at the rate of about 1 cubic yard to every 100 to 150 square yards of road surface. The size of the screenings or pea gravel should be such as will pass a $\frac{5}{8}$-inch screen and be caught on a $\frac{1}{4}$-inch. The screenings should be from hard stone, and should be free from dust and fine material. The harder the stone the smaller may be the screenings. The screenings are spread by hand with shovels or with a revolving-disk mechanical spreader. After being spread, particularly if the work is done by hand, the screenings should be carefully broomed to secure a uniform thickness of not over $\frac{3}{8}$ of an inch.

The purpose of the screenings is to keep the bituminous material from being picked up on the wheels of vehicles, to make the surface less slippery, and to increase the wearing qualities of the road.

595. After the screenings have been spread a few hours, it is advantageous to roll with a roller, preferably the tandem type, weighing between 8 and 15 tons; but the rolling is not vital.

596. VALUE OF BITUMINOUS CARPETS. Bituminous carpets on old water-bound macadam roads have been of great value in enabling such roads to carry a considerable amount of motor-driven traffic; and under some conditions it has been economical to build a new water-bound macadam road and cover it with a bituminous mat or carpet. Such a surface will usually last from 6 months to 2 years depending upon the amount and kind of travel. Bituminous surfaces have not been as successful on gravel as on macadam, perhaps because the former are more difficult to clean; but with care a fair degree of success can be insured on gravel.

597. Many attempts have been made to add a bituminous surface to a portland-cement concrete road, but with widely varying degrees of success. The concrete road ordinarily has a large amount of travel, and therefore usually has too many steel-tired horse-drawn vehicles for a bituminous carpet. It seems to be agreed that the following conditions are important: 1. The concrete itself must be good. 2. The concrete surface should be roughened by wear before the bituminous coating is applied. 3. The surface of the concrete must be warm, dry, and clean when the bituminous material is applied. 4. A preliminary priming or paint coat of thin tar is

advantageous. 5. Two thin coats of the carpet material are better than a single thick one. 6. A ½-inch coating can not stand up under much horse-drawn traffic. If there is much horse-drawn traffic, it may be necessary to make the coating 1 to 1½ inches thick by applying several successive layers of tar and screenings. Possibly a bituminous material will yet be made that will be more suitable for such use.

The advantages of a bituminous surface on a concrete road are: 1. It protects the concrete from wear. 2. It reduces the noise from the impact of horses' shoes and steel-tired wheels. 3. It removes the glare of the light-colored concrete. 4. It hides the black blotches made in filling the cracks and joints.

598. Maintenance of Bitumen Carpets. The work of maintenance consists in patching the carpet where it wears through or peels up, and in removing bunches where the carpet has crawled. The patching is easily done by following the method employed in the original construction; but care should be taken that the spot to be covered is clean, dry and warm.

It is not easy to remove the bunches. If the surface is soft, a scraping grader (§ 155) will sometimes smooth the surface without peeling up the carpet; but the work must be done during warm weather and immediately after a rain. The bunches may be removed by hand with a shovel that is kept hot while in use; but the shovel will not last long. A sharp chisel-like cutting tool if made of heavy metal will stand heating better than a shovel, and will remove the bunches. The bunch can be softened by building a small fire of twigs over it, or by pouring kerosene over it; but this practice is likely to ruin the material for some distance around the bunch. There are surface heaters, i. e., a hood having a gasoline flame under it, which are used for removing sheet asphalt (Fig. 161, page 451), which can be employed for removing these bunches; but the process is slow and expensive, and the flame is likely to damage the material which is not removed.

599. Cost of Bituminous Carpet. Before the recent disturbance of prices by the Great European War, the cost of oils or tars for bituminous carpets varied according to the grade of the material from 4 to 16 cents per gallon, but usually from 6 to 8 cents. In some states the total cost of a bituminous carpet has been as low as 3 cents per square yard, while in others it has been as high as 15 or 20 cents.

Below are the details of the cost of applying a light bituminous

carpet to a gravel road and to a water-bound macadam road by the Illinois Highway Department in 1915.

600. Gravel Road. The cost at Cairo, Illinois, of applying 0.5 gallon of cold oil (Aztec liquid asphalt) containing 60 to 65 per cent of asphalt, and 0.006 ton of torpedo gravel, stone chips, and sand per square yard, to a gravel road $1\frac{1}{2}$ miles long, the average haul being 0.5 mile and the rate of pay for laborers being 15 cents per hour and for teams 40 cents, was as follows:*

Items.	Cost Cts. per Sq. Yd.
Oil, 8184 gallons at 4.7 cents f.o.b. siding	2.34
Torpedo gravel at 59 cents per cubic yard, f.o.b. siding	0.24
Heating and applying oil, demurrage, etc.	0.32
Hauling gravel 0.5 mile and spreading	0.31
Sweeping and cleaning old road	0.034
Freight on equipment	0.54
Superintendence, engineering, and inspection	0.21
Total, exclusive of depreciation, over-head expense, and profits	3.99

601. Macadam Road. The cost of applying a bituminous carpet consisting of 0.33 gallon of Trinidad B asphalt and 0.016 ton of torpedo gravel per square yard, the average haul being $1\frac{1}{2}$ miles and the pay of laborers being 25 cents per hour and of teams 50 cents, was as follows:†

Items.	Cost Cts. per Sq. Yd.
Field superintendence	0.35
Bituminous material @ 7.7 cts. f.o.b. siding	2.39
Torpedo sand @ 1.825 per ton f.o.b. siding and stone chips @ $.140	2.67
Hauling gravel and chips, $1\frac{1}{2}$ miles	0.84
Spreading gravel and chips	0.56
Sweeping and cleaning old road	0.05
Heating and applying material, demurrage, etc.	1.04
Freight and equipment	0.15
Repairs to equipment	0.07
Incidental expense	0.22
Patching holes and repairing culverts	0.27
Total, exclusive of engineering, inspection and rent of equipment	8.61

602. State Reports. The annual reports of many of the State Highway Departments give detailed data of the cost of bituminous

* *Illinois Highways*, December, 1915, p. 168; or *Engineering Record*, Vol. 73 (1916), p. 806.
† *Illinois Highways*, December, 1915, p. 171.

road surfaces. For example, the 1915 report of the New York Commissioner of Highways, pages 177–94, shows the kind and quantity of bituminous material used, its cost, the amount applied per square yard, the area covered, the cost of labor, and the total cost for each road in each county treated in that year—a total of 1800 miles.

CHAPTER X

BITUMINOUS MACADAM AND BITUMINOUS CONCRETE ROADS

604. A bituminous-macadam road consists of two or more courses of broken stone, the wearing course of which is bound with bituminous cement applied on the surface. Formerly this form of construction was usually called bituminous macadam by the penetration method, but sometimes simply penetration macadam.

A bituminous-concrete road consists of one or more courses of broken stone, the wearing course of which is bound with bituminous cement mixed with the stone before it is placed. Formerly this type of construction was usually called bituminous macadam by the mixing method, but sometimes simply mixed macadam.

Since in both of these types of construction the binder may be either tar or asphalt, it would be appropriate and more definite to use the specific terms asphalt macadam or concrete, and tar macadam or concrete; and further it would not be inappropriate to use the terms native-asphalt and residuum-asphalt macadam or concrete; and likewise coke-oven tar macadam or concrete, and water-gas tar macadam or concrete. For a distinction between bituminous concrete and asphalt concrete, see § 891.

The present use of the terms bituminous macadam and bituminous concrete is based upon the analogy between the method of construction of these roads and that of macadam and concrete, respectively.

605. The two methods of road construction considered in this chapter have come rapidly into use since about 1910.

Art. 1. Bituminous Macadam Roads

606. The drainage and the preparation of the subgrade is substantially the same as for the forms of roads already discussed.

607. Foundation. The foundation is often an old gravel or macadam road, usually the latter; and sometimes, though less

frequently, a new gravel or macadam road is constructed for the purpose; and occasionally a portland-cement concrete foundation is used.

If the foundation is an old water-bound macadam road, the surface should be swept with a machine broom. All fine material that is caked upon the surface and is not removed with the machine broom should be loosened by hand, and then the surface should be swept perfectly clean with a hand broom. The coarse stone should be exposed, so the bituminous binder may adhere well.

If the foundation is a new macadam road, it should be constructed as described for water-bound macadam roads (Chapter VI). Under the same conditions, the total thickness of the road, including the bituminous wearing course, may be a little less than that of a water-bound macadam road, as the bituminous top will not wear as rapidly as the water-bound, since the former is usually built where motor-driven traffic predominates and rubber tires have but little effect upon the bituminous top. The first and second courses of stone are laid, rolled, filled, sprinkled, and again rolled as described for water-bound macadam, except that the second course is not flushed, i. e., is not filled so much as to form a film over the surface. It is essential that there shall be no voids in this course to absorb the bituminous binder. The stone should be clean and dry when the binder is applied.

608. WIDTH. For a discussion of matters relating to the width and position of the improved wheelway, see § 95–97.

609. MAXIMUM GRADE. For a discussion of maximum grades, see § 79–85; and for recommended values for the maximum grade, see Table 15, page 57.

610. THE CROWN. The crown for bituminous macadam should be less than for water-bound, $\frac{3}{8}$ of an inch to the foot being enough. See Table 16, page 66.

611. WEARING COAT. The wearing coat consists of a layer of $1\frac{1}{4}$-inch to $2\frac{1}{4}$-inch stone and two applications of asphaltic cement or refined tar, each of which is followed by a layer of $\frac{5}{8}$-inch to $\frac{1}{4}$-inch screenings. If the stone is soft, the size of the screenings may be a little greater than stated above; and if hard, a little less.

The layer of stone should be evenly spread to such a depth that after rolling it will have a thickness of $2\frac{1}{2}$ inches, and should then be rolled dry until the fragments have become firmly keyed together so that the stones will not move ahead of the roller or so that they can not be moved by the thrust of a man's heel. If the foundation

is new macadam (§ 607), this course should be spread and rolled while the top course of the foundation is still moist and soft; but should not be rolled so much as to force the slush of the foundation more than half way up into the voids of the course being laid. Fig. 98 shows the rolling of the layer of stone of the wearing coat in progress. It is important that this course be not rolled so much as to prevent the penetration of the bituminous binder; and on the other hand, the course should not be so open as to require too much

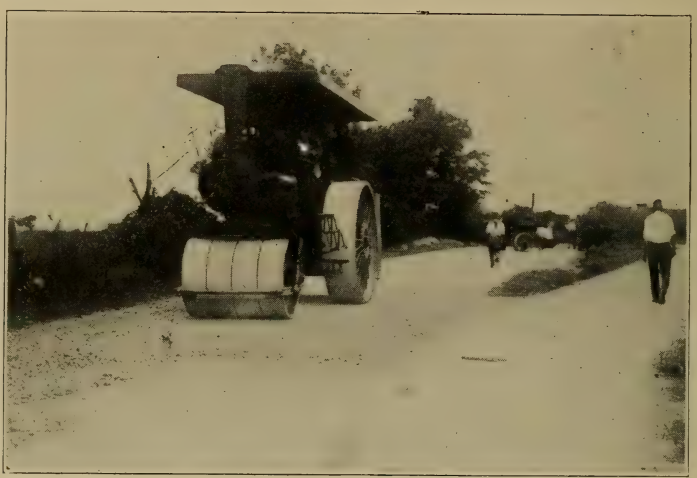

FIG. 98. ROLLING OF LAYER OF STONE FOR WEARING COAT.

binder to fill the voids. If the stone is hard, it may be necessary after the rolling is partly completed, to fill the voids by applying a coat of gravel, see Fig. 99.

612. BITUMINOUS BINDER. The bituminous binder may be either asphaltic cement or refined tar. The asphaltic cement should meet some one of the specifications in § 537–38; and the tar should meet one of two specifications in § 572–73. Owing to its greater cementing value asphalt is better for a road to be subjected to heavy horse-drawn loads than tar.

The asphaltic cement when applied should have a temperature of 135 to 177° C. (275 to 350° F.); and the tar of 93 to 121° C. (200 to 250° F.).

The amount of bituminous cement for the first application should be just sufficient to penetrate the third course and fill all of the voids; and usually this will require about 1 gallon per square yard per inch

of thickness of the upper course; and for the second application from $\frac{1}{2}$ to $\frac{3}{4}$ gallons per square yard. An excess of binder is not only expensive, but causes the wearing course to creep and form waves.

613. Applying the Binder. For small jobs or where it is difficult to operate tank wagons, the bituminous material is shipped in barrels or drums, heated in open kettles, and applied by hand from pouring cans. For the best results, the binder should be hauled in tank wagons provided with a heater, one or more thermometers, and a

FIG. 99. FILLING LAYER OF STONE WITH GRAVEL.

pump for distributing the binder under pressure in the form of a spray. The tank wagon must have wheels with tires so wide as not to make an appreciable rut in the surface of the road. The spreading must be done so as to secure absolute uniformity. The area covered with a barrel- or a wagon-load should be measured, and the rate of application computed. After the binder has been applied, the surface should be uniformly black, but the spaces between the stones should show. The temperature of the stone or the air should not be less than 50° F. (10° C.) during the application.

After the first coat of binder is applied, a layer of $\frac{1}{4}$-inch to $\frac{3}{4}$-inch stone screenings, not over $\frac{3}{8}$ of an inch thick, is spread over the surface; and then the road is rolled. If there is an excess of uncemented screenings after the rolling, they should be removed with a push broom, for an excess will cause the seal coat (the last coat of binder) through lack of adhesion to the first coat, to peel off.

After applying and rolling the screenings, a seal coat of $\frac{1}{2}$ to $\frac{3}{4}$ gallons of binder per square yard is spread by the same means as for the first coat; and the utmost care should be taken to put on the material uniformly.

Finally, the road receives a coat of screenings of hard screenings or pea gravel, not over $\frac{3}{8}$ of an inch in thickness; and is again rolled. The rolling is continued until a smooth surface is produced. The road is now ready for travel.

The eight views in Fig. 100 show the various steps in constructing the wearing cost of a bituminous macadam road.

614. ANOTHER TYPE OF BITUMINOUS MACADAM. The wearing course of the preceding type of bituminous macadam road could be appropriately described as a course of stone grouted with bituminous cement. The Massachusetts Highway Commission and others sometimes use a mixture of tar and sand for the grout instead of a neat bituminous cement. It is claimed that the sand materially stiffens and strengthens the road crust and decreases the oxidation of the tar.

Fig. 101, page 312, shows two views of the construction of a tar-sand macadam road built by the Massachusetts Highway Commission.

615. CHARACTERISTICS OF BITUMINOUS MACADAM. This form of construction is adapted to roads having a moderate amount of travel with not many heavy horse-drawn loads on narrow tires. It has a pleasing appearance, and is well adapted to both horse-drawn and motor-driven traffic. The surface seems to deteriorate more rapidly where considerable quantities of mud are tracked on it. In warm weather, particularly if an excess of binder was used, there is a tendency for the surface to creep and develop undulations.

There have been a considerable number of failures of bituminous macadam roads, apparently because of the neglect to observe the proper methods of construction,—perhaps through lack of knowledge, since the type is comparatively new.

616. COST. This form of construction usually costs about 15 to 20 cents per square yard more than good water-bound macadam (§ 388–93). There has not yet been sufficient experience to determine the cost of maintenance or the ultimate life of the bituminous layer.

617. MAINTENANCE. Bituminous macadam is peculiarly resistant so long as it is intact; but when once broken, due to defective materials or workmanship, or to wear of travel, or to the opening of a

1. Spraying Tar on Layer of Stone. 2. Spreading ⅜-inch Stone on First Coat of Tar

3. Sweeping Screenings to Secure Uniform Distribution. 4. Rolling after Spreading Screenings.

5. Spraying Seal Coat of Tar. 6. Putting Screenings on Seal Coat.

7. Final Rolling of Road. 8. Finished Road.

FIG. 100.—CONSTRUCTING WEARING COAT OF TAR-MACADAM ROAD.

trench, it disintegrates rapidly. Under these circumstances the defective portion should be cut out, the sides and bottom of the hole coated with bituminous cement, and the hole filled with stone and cement well mixed and solidly tamped into place. It is well to leave

1. Roller, Tank Wagon and Mixer. 2. Pouring Tarvia-Sand Grout.

FIG. 101.—CONSTRUCTING TAR-SAND MACADAM ROAD.

the patch a little high, so it will not be low when finally consolidated by travel.

If the surface of the road becomes dry and lifeless, a new seal coat should be applied at once. This will usually occur with a tar binder in two or three years, depending upon the amount and character of the travel; and with an asphalt binder, in three or four years. Applying a new seal coat is peculiarly a case in which a stitch in time saves nine.

ART. 2. BITUMINOUS CONCRETE ROADS

619. In the form of construction considered in this article, the wearing course consists of a layer of crushed stone bound together by either tar or asphalt. The stone and the binder are usually heated before being mixed, and are laid while hot.

The distinction between bituminous concrete as considered in this article and asphaltic concrete as considered in connection with asphalt pavements (Art. 2, Chapter XVI), is that in the latter the binder is always asphalt, and the aggregate is accurately graded so as to secure a minimum of binder and also a maximum stability. One form of construction gradually shades into the other, and it is impossible to draw a definite line between them. In the accurate gradation of the aggregates asphalt concrete is closely related to sheet pavements, and hence the two are considered together in Chapter XVI.

620. All that was said in § 114–28 concerning drainage, subgrade, and crown applies also to bituminous concrete roads.

621. THE AGGREGATE. Gravel may be used, but only for light traffic. Broken stone is generally used because of the better bond thus secured. The broken stone should be hard and of compact texture and uniform grain, be free from adhering fine material, and preferably should have rough surfaces and sharp angles.

Bituminous concrete is sometimes laid with crusher-run stone; but since the stone is not so uniform, the result is not so good as where graded stone is used.

For the best results the aggregate should be carefully graded. "Practice has demonstrated that a mineral aggregate which will comply with the following sieve analysis, using screens having circular openings, will produce satisfactory results: All the material shall pass a $1\frac{1}{4}$-inch screen; not more than 10 per cent nor less than 1 per cent shall be retained on a 1-inch screen; and not more than 10 per cent nor less than 3 per cent shall pass a $\frac{1}{4}$-inch screen."*

For a more full discussion of the grading of the mineral aggregate for bituminous concrete, see Art. 2, Chapter XVI—Asphalt Pavements.

622. THE BINDER. The bituminous cement used in the mixing may be either tar or asphalt cement; but the seal coat should always be asphalt cement (§ 541). The tar should conform to the specifications in § 574–75; and the asphalt cement should meet the requirements stated in § 539–40.

The quantity of bituminous cement to be used in the mix will depend on the gradation of the broken stone and the character of the bituminous cement, the climatic conditions, etc. For an aggregate graded as in the preceding section, the mixture should contain between 5 and 8 per cent by weight of bitumen.

623. MIXING THE CONCRETE. There are two types of mixing, cold and hot.

624. Cold Mixing. This method is employed only with a special grade of tar, and the concrete is usually mixed by hand. This method is not very common, and great care is necessary in using it. The stone must be perfectly dry, the weather must not be too cool, and there should be a considerable period of warm weather immediately following the completion of the road. This form of construction is suitable for light traffic; but not for heavy traffic, either horse-drawn or motor-driven.

* Report of Committee of Amer. Soc. of Civil Engineers, Proc. Vol. 42 (1916), p. 1626.

625. Hot Mixing. Usually the stone and binder are heated separately and then mixed in a machine mixer.

Bituminous concrete can be mixed in an ordinary hydraulic-cement concrete mixer; but mixers specially designed for mixing it are much more satisfactory. There are various such mixers on the market. Some mixers are heated internally by an open flame, and others externally by a flame or steam. On account of the danger of burning the cement, the flame in the mixing chamber should not be used, except perhaps on small jobs and in repair work; and even then the flame should never be allowed in the mixer after the bituminous material has been added.

The heating device should be easily regulated, so that there will be no danger of burning the binder. The most common cause of failure in bituminous concrete roads is the burning of the binder. A burned batch will not usually show when laid, but after a few months will reveal itself.

626. The bituminous cement, if asphalt, is usually heated to about 135° to 177° C. (275° to 350° F.); and if tar, from 93° to 135° C. (200° to 275° F.). The stone for the asphalt mixture is heated to about 150° C. (302° F.), and that for the tar mixture to about 100° C. (212° F.). Any asphalt or tar that is heated more than stated above should not be used. No tar should be heated in a kettle containing any asphalt, and likewise no asphalt should be heated in a kettle containing any tar; and any mixtures resulting from this cause should be rejected.

When discharged, mixtures of asphalt cement and broken stone should have a temperature of not less than 93° nor more than 149° C. (200–300° F.). When discharged, mixtures of refined tar and broken stone should have a temperature of not more than 121° C. nor less than 66° C. (250–150° F.).

The mixer should be designed and operated so as to produce a thoroughly coated and uniform mixture without any segregation of the stone and the cement.

Bituminous concrete should not be mixed or laid when the temperature of the air in the shade is less than 50° F. (10° C.).

627. Laying the Concrete. If not mixed upon the street, the concrete should be hauled in canvas-covered wagons or trucks; and should be delivered at a temperature of at least 66° C. (150° F.). The hot mixture should be dumped upon platforms, shoveled into place with hot shovels, immediately raked to a uniform thickness, and then thoroughly compacted by rolling. The roller should be of

the self-propelled tandem type weighing from 10 to 12 tons, and giving a compression under the rear roll of 250 to 350 lb. per linear inch. The rolling should continue until all roller marks disappear.

After rolling, the wearing course should have a uniform thickness. The experience with this type of construction is somewhat limited, but apparently a thickness of $1\frac{1}{2}$ or 2 inches is sufficient to stand the heaviest mixed traffic; and apparently a greater thickness is unwise, since it has a tendency to creep and form bunches. The surface should be free from depressions and irregularities exceeding $\frac{3}{8}$ of an inch under a 4-foot straight edge laid longitudinally.

628. Seal Coat. As soon as possible after the completion of the rolling, and while the surface is dry and clean, a seal coat of hot asphalt cement should be applied with a hand-drawn distributor, and be spread with a squeegee. The asphalt cement should meet the requirements in § 541; and should be applied at a temperature of not less than 135° nor more than 177° C. (275–350° F.) at a rate of $\frac{1}{2}$ to 1 gallon per square yard.

As soon as possible after the application of the seal coat, and not more than 20 minutes thereafter, a thin uniform layer of stone chips ($\frac{3}{8}$- to $\frac{1}{4}$-inch or $\frac{1}{2}$- to $\frac{1}{4}$-inch) should be spread and thoroughly rolled with the tandem roller described in § 378.

Fig. 102, page 316, shows six views of the construction of a bituminous concrete road built in Pennsylvania. The maximum size of the aggregate in this case was that passing a $\frac{1}{2}$-inch mesh; and hence the concrete could be leveled off by striking with a template—see view 3. Views 5 and 6 are included partly to fill out the plate and partly to show the two forms of distributors.

629. Maintenance. See § 617, page 310.

630. Cost. Under similar conditions, the cost of this type of road is usually about 20 to 25 cents more than that of water-bound macadam (§ 388–93).

631. Comparison of Bituminous Macadam and Bituminous Concrete. Bituminous macadam is the more common, there being seven or eight times as much in use as bituminous concrete.

The *advantages* of bituminous macadam are: 1. It is comparatively cheap. 2. It requires no expensive machinery. 3. It is easily and quickly laid. 4. The cost for labor is comparatively low. The *disadvantages* are: 1. Considerable care is required to prepare properly the upper course of the foundation to receive the bituminous macadam. 2. There is difficulty in securing a uniform

distribution of the binder through the wearing coat. 3. It is practically necessary to use an excess binder, and hence the surface may creep under traffic. 4. The quality of the binder must be sac-

1. Loading End of Mixers. 2. Discharging End of Mixers.

3. Striking Tar-Concrete. 4. Rolling Tar-Concrete.

5. Applying Seal Coat. 6. Applying Seal Coat.

FIG. 102.—CONSTRUCTION OF TAR-CONCRETE ROAD

rificed to the requirements of the method of its application. 5. The method is not applicable in cold or damp weather.

632. The *advantages* of bituminous concrete are: 1. It permits a perfectly uniform distribution of the binder. 2. It permits the use

of a suitable quality and quantity of binder. 3. It can be laid in comparatively cold weather. The *disadvantages* are: 1. The cost of the labor is comparatively high. 2. It is slow in application. 3. A considerable quantity of expensive machinery is required. 4. The total cost is somewhat greater.

PART II

STREET PAVEMENTS

633. Good pavements are necessary to the highest development of the commercial, sanitary and esthetic life of a city. The large proportion of people now dwelling in cities makes the subject of pavements an important one; and the fact that the urban population is increasing much more rapidly than the rural, and also the fact that the public is awakening to the necessity of ameliorating the condition of life in the city, will make pavements of increasing concern in the future.

CHAPTER XI

PAVEMENT ECONOMICS AND PAVEMENT ADMINISTRATION

Art. 1. Pavement Economics

634. Benefits of Pavements. The effect of pavements upon city life is so important and so far reaching that no enumeration is likely to include all of the benefits; but nevertheless it will be of advantage, particularly in discussing the proper distribution of their cost, to enumerate some of the more important of the benefits resulting from the construction of pavements. Briefly the principal advantages are:

1. Good pavements lessen the tractive power required, and decrease the cost of transportation. See § 4–9 for a discussion of the cost of transportation.

2. Good pavements increase fire protection by facilitating the transportation of the fire apparatus.

3. Pavements establish a permanent grade, which is an important matter when other improvements are to be made.

4. Pavements improve the appearance of the street by giving a uniform surface instead of the irregular one of an unpaved street.

5. Pavements increase cleanliness, since the pavement is less dusty in a dry time and less muddy in a wet time than an unpaved street, and since they are easily cleaned.

6. Pavements increase healthfulness by removing holes filled with mud and filth.

7. Pavements permit pleasure driving at all seasons, and facilitate social intercourse.

8. Pavements allow the use of bicycles, which furnish to many cheap transportation and healthful recreation.

635. In discussions of this subject it is customary to include the enhanced value of the adjacent property as one of the advantages of a pavement; but the increase in the value of the property is simply a measure of the benefits enumerated above, and hence should not again be included.

The first three benefits above may be regarded as financial advantages and the last four as sanitary and esthetic. It is impossible to compute even approximately the financial, much less the sanitary and esthetic, value of good pavements; but it is safe to say that they are an absolute necessity to both the business and residency of the larger cities and also for business districts of the smaller cities, and that on residence streets of small cities good pavements add greatly to the health, comfort and pleasure of life.

636. INVESTMENT IN PAVEMENTS. The table on page 320 was compiled from statistics published by the U. S. Census Bureau, and shows the total areas and cost of the different kinds of pavements in 1909 in the 158 cities having a population of over 30,000.* The areas are probably reasonably accurate, but the unit prices are only approximate owing to failures to state what was included in the cost, i. e., whether or not it included grading, foundation, curb, gutter, etc.

From this table it appears that the pavements in these cities have cost $695,936,294; and as the total population is 25,603,949, the pavements have cost $27.10 per capita. The area of pavements per capita varies greatly in the different cities, being practically independent of the size and location of the city; but the average seems to agree fairly well with the area of pavements in a number of very much smaller cities investigated by the author. Therefore, it

* General statistics of cities for 1909, Bureau of Census, Washington, D. C., 1913.

will be assumed that the above average is representative of the entire country. According to the U. S. Census Report there were 41,717,853 people dwelling in cities of 8000 population or over in 1916. Therefore the investment in pavement in these cities amounts to $1,046,320,000. Measured by the money invested, street pavements, except steam railroads, are probably the most important of any single class of engineering construction.

INVESTMENT IN PAVEMENTS

Asphalt—sheet	83,227,011	sq. yd. at	$2.75 =	$238,874,281
block	5,418,666	"	2.75 =	14,901,331
Bithulitic	4,000,872	"	2.25 =	9,001,962
Brick	53,870,578	"	2.25 =	120,208,805
Cobble stone	9,083,397	"	0.80 =	7,166,718
Concrete, portland-cement	445,478	"	1.20 =	434,576
Gravel—water-bound	43,634,491	"	0.20 =	8,726,898
bituminous bound	4,674,605	"	0.40 =	1,869,842
Macadam—water-bound	107,998,789	"	0.75 =	80,998,082
tar-bound	3,008,919	"	1.00 =	3,008,919
portland-cement grouted	303,069	"	1.00 =	303,069
Stone block	51,414,901	"	3.50 =	179,950,183
Wood block—creosoted	2,936,047	"	3.00 =	8,808,141
untreated	10,724,370	"	2.00 =	21,448,740
Other kinds	4,367,708	"	.20 =	873,541
Total	385,409,889	"	=	$675,936,294

637. Data for the year 1899 similar to the above were presented in former editions of this treatise; and apparently from 1899 to 1909 the area of pavements increased 38 per cent, and the cost 71 per cent. The increase in area is due to the increase of pavements in each city and to the increase in the number of cities from 129 to 158. The increased cost is due chiefly to the increase in the area of pavements, but partly to the increase in the quality of the pavements and partly to the increased cost of labor and materials. The quality of pavements has increased greatly in the last few years. For example, formerly stone-block pavement consisted of roughly dressed blocks laid on a sand or gravel subgrade with wide joints filled with sand or pebbles; while now most stone-block pavements consist of accurately dressed blocks laid on a concrete foundation with close joints filled with bituminous or hydraulic cement. A corresponding improvement has taken place in most other forms of pavements. However, the cost of pavements has not usually increased proportionally, owing to improvements in methods of doing the work. Some of

these improvements are: The cutting of granite blocks largely by machinery instead of wholly by hand; the use of the 4-wheeled scraper and the steam shovel in preparing the subgrade; improvements in the methods of handling and delivering the sand and gravel for the foundation; the mixing of the concrete for foundations by machinery instead of by hand; improvements in the methods of handling the pavement materials, etc.

638. According to Bulletin No. 100 of the 1890 census, the average annual expenditure for pavement construction and repairs in the cities of the United States having a population of 10,000 or over, was $1.72 per capita, being $1.54 in the cities having more than 100,000 population and $2.04 in cities from 10,000 to 100,000. No later data seem to have been collected. If the same rate of expense obtained in 1909, the total annual expenditure for pavements in cities of 8,000 or more population was $85,104,420. In some smaller cities the average normal expenditure for pavements is four to five times the average just stated.

The first cost of pavement and also the annual cost is of such magnitude that merely as a financial question, street pavements deserve careful attention and systematic study.

ART. 2. PAVEMENT ADMINISTRATION

640. IMPORTANCE OF PROBLEM. The importance of pavements as an element in municipal finance seems not to be fully appreciated, and this subject has not received from municipal engineers and city officials the attention and study its importance merits. Whether measured by their influence upon the commercial, sanitary or esthetic life of the city, or by the amount of money invested in them, street pavements belong in the first rank of importance in municipal affairs.

641. Present Conditions. The following quotation * shows the surprising attitude of the public and municipal officials toward this important subject.

"One would suppose that a subject of the magnitude and importance of pavements would be a matter of the most critical investigation and scientific research; but it is safe to say that in no other branch of civil engineering is there expended so large an amount of

* John W. Alvord, C.E., in "The Street Paving Problem of Chicago." A Report to the Commercial Club of Chicago, 1904.

money in so unsystematic a manner, and generally with such unsatisfactory results.

"Pavements are primarily designed to accommodate travel; but scarcely any one in this country thinks of investigating the travel of a city systematically and thoroughly before proceeding to lay pavements.

"Pavements are financial investments; yet few city officials before proceeding to raise the necessary capital, undertake to compile data from which to compute the cost of maintenance and the length of life or depreciation.

"Street pavements are by far the most expensive single improvement that the municipality undertakes; yet in hardly any of the cities of this country are there suitable laws, proper organization, or sufficient public spirit adequately to care for the investment after it is once made.

"The improvement of streets is a legitimate method of adorning our cities; yet no one thinks of consulting recognized authorities on good taste in such matters, except in boulevards and parks.

"Pavements have been a necessity of civilization since Rome was mistress of the world; but cities are still experimenting with the subject without general and well-defined policies. Community after community repeats the fundamental experiments, and copies without reflection or study what it sees being done elsewhere.

"The managers of the railways of the country know to a cent the cost and the comparative utility of every bolt and scrap of iron that enters into their road; and they can tell to several places of decimals of a cent the cost of moving a ton of freight or the cost of transporting a passenger a single mile. But the city officials in this country that can make more than a rough guess of these matters in connection with the enormously greater travel of cities, can be counted on the fingers of one's two hands."

642. Causes of Present Conditions. The present anomalous conditions are due to the following causes:*

1. "The administration of American cities change every few years; and seldom do officers of the municipality have the ambition or opportunity to become thorough masters of the broader requirements of the problems with which they are confronted.

"2. In a republican state the tax-payer is expected to have a deciding vote in the expenditure of the public moneys, especially

*John W. Alvord, C. E., The Street Paving Problem of Chicago. A Report to the Commercial Club of Chicago, 1904.

those raised by local taxation. As a result, advancement proceeds no faster than the education of the whole mass of tax-payers.

" 3. Different kinds of street pavement rise or fall in public estimation with an undue amount of popular fluctuation. This is because there is no pavement that is perfect for all classes of conditions; and the pavement that comes the nearest to meeting one set of requirements may be the furthest away from another set of requirements. The public having selected a pavement, perhaps ill adapted to a particular environment, and finding it lacking in important particulars, is apt to thoughtlessly, and perhaps pettishly, condemn it *in toto* when such a sweeping verdict is not warranted. Even city officials in charge of such matters do not always investigate carefully enough the causes which make for failure, and allow personal impressions to take the place of carefully investigated facts.

" 4. The engineers of this country, up to within a few years, have not generally interested themselves in the subject of street paving, because they have not been given very good opportunity to properly study the question. Finding the tax-payer a self-appointed and sometimes exacting authority, they have been obliged more or less to abandon the field, so far as its broader questions are concerned, and accept his dictum. The specialist on street paving has been long recognized abroad as an important factor in municipal progress; and of recent years, he is beginning to appear in the United States. Seldom, however, does an average city call for his services; and almost never do municipalities appoint commissions of such men with ample funds to make an exhaustive study of the street-paving problem in its broader requirements.

" 5. The natural distrust for municipal authorities is the normal condition of mind of the American tax-payer. This is the inevitable result of a system that generally produces mediocre results. And nowhere are mediocre results more apparent and unhappy than in the work of street improvements. As a result, the average city administration, however honest its intentions, feels that it is without moral support. It does not initiate broad policies, or spend public moneys for investigation and research; but it gropes its way in the darkness of chance, and plays its cards like an opportunist, postpones all possible trouble to its successors, and blames all deficiencies onto its predecessors, while ever pleading for revenue for new experiments. A distrustful public generally refuses to cooperate in legislation tending to increase taxation for the future, until absolutely

assured of wisdom and economy in the present. The public is at times a harsh judge, and does not easily overlook glaring imperfections or fully analyze deficient results.

" 6. The usual method in this country of assessing the cost of improvements to the abutting property has tended to give undue prominence to the property owner, as the representative of the public in deciding upon and paying for street paving. As a matter of fact, the abutting property owner is an agent. Whenever possible he passes on to the rest of the community, in the form of increased valuation and rental of his property, the cost he is assessed. Often he recoups himself for his outlay many times over; and yet ordinarily he regards himself as a public benefactor, and as such claims the right to outline street policies which usually lead to his own pecuniary advantage rather than to that of the public.

" 7. The method of assessing the first cost of pavements on the property owner, and then maintaining the pavement out of the public fund, has resulted in the majority of cases in there being little, if any, maintenance. No municipality has ever had an adequate 'general fund.' The general fund is the common prey of all the more novel municipal projects and ambitions; and the commonplace uses to which it might be put will always be unduly curtailed.

" 8. There is no general public appreciation of the vital necessity of maintaining pavements after they are once laid; and as a consequence there has been no cooperation on the part of the public in framing legislation and raising revenues for this purpose. In this country, the practice has been generally to build pavements at high first cost, and allow them to wear out with a minimum of repair.

" 9. Finally, in this country the street-paving problem is everywhere regarded as a local or neighborhood problem. The general public has not yet come to regard it as a national problem, or even entirely a municipal problem; and hence the lack of appreciation of the broader municipal requirements, and the insufficiency of study of its fundamental principles. To this cause may be assigned the chaotic condition of the art and incoherence of the data now existing and the absence of any general principles which should govern the subject as a whole."

643. Remedy of Present Conditions. The present unfortunate conditions could be largely remedied by making the investigations and by carrying out the policies mentioned below.

1. The first requirement for a comprehensive plan for street pavements should be a study of the traffic conditions of the entire

city, which should include a census of the origin, amount, character, direction, and density (the amount per foot of width of street or pavement) of the travel on representative streets in all parts of the city.* Such a census should be repeated at regular intervals so that the growth and tendency of the traffic may be known with as much certainty as vital statistics or the census of population, since only by so doing can a basis be found for sound present policies or for forecasting future necessities. It is not possible to formulate any scientific and adequate plan for street pavements without knowing the present and prospective use to be made of the pavements. Unfortunately, but few such census data have been obtained for any American city—see § 34.

2. The streets should be classified as to the amount and character of the travel, the width of pavement, the depth of foundation, the kind of wearing surface, the amount necessary for maintenance, etc. The highway departments of the several states have recently quite generally classified the rural roads according to the amount of travel, and have specified certain types of road surfaces for the different classes of roads—for example, see Table 26, page 177.

3. Careful records should be kept of the cost of repairs on different kinds of pavements under different traffic conditions; and an inventory should be made at stated intervals to determine whether or not a particular pavement is gradually deteriorating, which would serve as a rough check upon the sufficiency of the annual repairs.

4. Careful records should be kept of the cost of cleaning different kinds of pavements under different traffic conditions. The cost of cleaning is a part of the cost of maintenance; and unless the annual cost of maintenance is known, it is impossible to compare accurately the total cost of different kinds of pavements.

5. Observations should be made to determine the tractive force required to draw loads over different types of pavements. There are tables of tractive resistance for different road and pavements surfaces,—for example, see Table 7, page 20;—but such data are quite general and do not represent with sufficient accuracy the pavements for a particular city which are built under certain specifications and of materials more or less local. The railways of this country spend large sums to determine the tractive resistance on tracks of different types and under different conditions; and the results of such observations are of great importance in maintaining an economic

* For a discussion of travel census for rural roads, see § 29–33.

relation between the cost of the up-keep of the track and the cost of drawing trains over the track. Corresponding data for street pavements would be helpful in determining when the condition of any pavement renders it unfit for further profitable use.

6. The public should be educated as to the financial, sanitary, and esthetic importance of street pavements; and also as to the fact that the construction and maintenance of pavements should be left entirely to those who have made a careful study of such work.

7. The laws should vest the power to determine when a street should be paved and to select the kind of pavement in either an elective board of long tenure so that its members may have an opportunity to acquire knowledge of paving materials and policies, or in a commission of real experts appointed for that purpose.

644. APPORTIONMENT OF THE COST. There is much discussion as to who in equity should bear the cost of the pavement. There are three distinct views.

1. A few claim that as they own neither a horse nor a vehicle and do not use the pavement, they should not be required to pay for it. Although a resident may not travel upon the pavement, it is used by those who serve him; and a pavement confers other benefits besides those relating to transportation. It is entirely impracticable to distribute the expense according to the use made of the pavement.

2. Others claim that the pavement is for the benefit of the general public of the city at large, and hence the abutting property should pay no more than that in other parts of the city. This claim ignores the fact that the abutting property secures a distinct benefit for which it should be required to pay. Laying at least part of the cost upon the abutting property tends to discourage a demand for lavish expenditures for unnecessary improvements, that possibly might be insisted upon if the city contributed the entire cost.

3. Many hold that the benefits accrue only to the abutting property, and that therefore the owner of the abutting property should bear the entire cost. This claim disregards the fact that the pavement is for the use of the general public, and benefits all the people and all those having business interests in the city. An improvement in any part of the city is an indirect benefit to the city as a whole. In excuse of this method of payment, it is sometimes claimed that, although the pavement confers a general benefit, the inequality will be compensated when all the streets are paved. The answer is that all the streets may never be paved, and besides traffic naturally concentrates on certain lines and nearly ignores certain others,

and therefore some pavements will require much more care and expense than others. Further, there should be no objection to letting every property holder pay a part of his ultimate share as the work progresses, instead of paying it in a lump sum when the street in front of his own property is paved. The second or third view or a combination of them usually obtains (§ 645). Table 36, page 328, shows the method of apportioning the expense in fifty American cities.*

The practice is slightly different for the grading, the original paving, and the re-paving. All of the cost of grading in 54 per cent of these cities is paid by the abutting property, in 32 per cent all by the city, and in 14 per cent part by each in varying proportions. The cost of the original paving in 62 per cent of the cities is charged entirely to the private owner, in 22 per cent entirely to the city, and in 16 per cent it is divided between the two. The cost of re-paving in 42 per cent of the cities is paid wholly by the property, in 40 per cent wholly from the general tax, and in 18 per cent it is divided between the two. In some cities a street in an addition or subdivision is not accepted by the municipal authorities until it has been graded, and hence it is done at the expense of the abutting property; but on the other hand, some cities are willing to bear a part of the cost of the street improvement, and therefore pay for the grading. Only one quarter of the above cities pay the major part of the cost of the original paving, while 40 per cent pay the major part of the cost of re-paving. It is the custom, where there is a car track on the street, to require the railroad to pave an 8-foot strip for each track, the remainder being divided between the abutting property and the city at large in the same proportion as on the streets where there is no track. In some cities intersecting streets are regarded as municipal property, and the cost of paving the intersection is assessed against the street, i. e., against the city; but in others the cost of paving the street intersections is included in the charge against the abutting property. In most cities lots owned by the municipality pay the same proportion of the cost of the street improvements as private property, although usually special authority is required thus to assess municipal property.

Table 36 also shows that as a rule the eastern and southern cities pay a larger proportion of the cost of pavements than do the western. This difference in practice is probably due chiefly to the

* From an article on Theory and Practice of Special Assessments by J. L. VanOrnum, in Trans. Amer. Soc. of Civil Engineers, Vol. 38, p. 336–422.

TABLE 36

Apportionment of Cost of Pavements in Fifty Cities

Ref No.	Locality.		Grading, Per Cent Paid by		Original Paving, Per Cent Paid by		Re-paving, Per Cent Paid by	
	State.	City.	Property.	City.	Property.	City.	Property.	City.
1	Alabama	Montgomery	50	50	50	50	50	50
2	Arkansas	Little Rock	100	...	100	...	100	...
3	California	San Francisco	100	...	100	...	.....	100
4	Connecticut	Hartford	.....	100	67	33	.....	100
5		New Haven	.....	100	*a*	.....	*b*	.....
6	Dist. of Columbia	Washington	.....	100	.....	100	.....	100
7	Delaware	Wilmington	.....	100	.....	100	.....	100
8	Florida	Jacksonville	50	50	50	50	50	50
9	Georgia	Atlanta	.....	100	67	33	67	33
10		Augusta	50	50	50	50	50	50
11	Illinois	Peoria	100	.....	100	.....	100	.....
12	Indiana	Indianapolis	100	*d*	100	*d*	100	*d*
13	Iowa	Burlington	.....	100	100	*c*	.....	100
14	Kansas	Topeka	.....	100	100	.....	100	.....
15	Kentucky	Louisville	100	.....	100	.....	.....	100
16	Louisiana	New Orleans	75	25	75	25	75	25
17	Maine	Portland	.....	100	.....	100	.....	100
18	Maryland	Baltimore	100	.....	100	.....	.....	100
19	Massachusetts	Lowell	100	.....	.....	100	.....	100
20		Springfield	.....	100	.....	100	.....	100
21		Worcester	100	.....	.....	100	.....	100
22	Michigan	Detroit	100	*c*	100	*c*	100	*c*
23	Minnesota	Minneapolis	.....	100	100	*c*	100	*c*
24		St. Paul	100	.....	100	.....	100	.....
25	Missouri	Kansas City	100	.....	100	.....	100	.....
26		St. Louis	.....	100	100	.....	100	.....
27	Nebraska	Omaha	50	50	100	*c*	100	*c*
28	New Hampshire	Manchester	.....	100	.....	100	.....	100
29	New Jersey	Newark	100	.....	100	.....	100	.....
30		Paterson	100	.....	100	.....	.....	100
31	New York	Albany	100	*d*	100	*d*	100	*d*
32		Brooklyn	100	.....	100	.....	50	50
33		Buffalo	100	.....	100	.....	100	.....
34		New York	100	.....	100	.....	.....	100
35		Rochester	100	.....	100	.....	100	.....
36		Syracuse	100	.....	100	.....	100	.....
37	Ohio	Cincinnati	98	2*c*	98	2*c*	98	2*c*
38		Dayton	100	*c*	100	*c*	100	*c*
39	Oregon	Portland	100	.....	100	.....	100	.....
40	Pennsylvania	Harrisburg	100	.....	100	.....	100	.....
41		Philadelphia	.....	100	100	.....	.....	100
42		Scranton	100	.....	100	.....	50	50
43	Rhode Island	Providence	100	.....	.....	100	.....	100
44	South Carolina	Charleston	.....	100	.....	100	.....	100
45	South Dakota	Sioux Falls	100	*c*	100	*c*	100	*c*
46	Tennessee	Nashville	.....	100	.....	100	.....	100
47	Utah	Salt Lake	50	50*c*	100	*c*	100	*c*
48	Virginia	Richmond	.....	100	.....	100	.....	100
49	Washington	Seattle	100	.....	100	.....	100	.....
50	Wisconsin	Milwaukee	100	*c*	100	*c*	.....	100

a. 1 sq. yd. for each front foot; city remainder.
b. 3½ sq. ft. " " " "; " "
c. City pays for street intersections.
d. City does not pay for street intersections.

limited revenues of new cities and to the many demands upon the general tax for the numerous and varied necessities of rapidly growing municipalities; consequently the cost of pavements, improvements having a definite local benefit, has been charged to the abutting property. It is equitable and just that the cost should be borne jointly by the private property and the city at large, since then the cost falls upon both interests which directly profit by the improvement, and neither receives a substantial benefit without sharing in its cost.

Ordinarily the proportion of the expense to be borne by the municipality and by the private property is determined wholly by financial considerations or usage, and is made uniform over the entire city; while equity and justice demand that a distinction should be made depending upon the character of the traffic. The interests of the general public in a street vary greatly between a residence street, a business street, and a general thoroughfare. To pave the first the public should pay only a small share, say, 20 or 30 per cent; for the second, say, 40 or 50 per cent; and for the third 60 or 75 per cent. Some such variation in the proportion to be borne by the two interests finds further justification in the fact that if the street becomes a general thoroughfare, some of the benefits enumerated in § 635 as accruing to the abutting property may be nullified by the noise and dirt.

646. Special Assessments.* The proportion of the cost of a pavement paid by the private property is usually collected as a special assessment, which has been defined as "a compulsory contribution paid once and for all to defray the cost of a special improvement to property, undertaken in the public interest, and levied by the government in proportion to the special benefits accruing to the property owner." Special assessments differ from taxes, both general and special, in that the former are based upon a direct and measurable benefit conferred upon the contributor, which is the measure of his liability to be taxed; while taxes are levied for the maintenance of the institutions and interests of the government, without reference to the particular benefits conferred, according to the ability of the contributor to pay. The construction of pavements to be paid for by special assessment must be done under the direction of the public officials.

* For an interesting and instructive dscussion of the history and theory of special assessments, see Special Assessments by Victor Rosewater—Vol. 2, No. 3 of Studies in History Economics and Public Law. 152 p., 6×9 inches, Columbia College, New York, 1893. See also the article referred to in the foot note on page 327.

In a general way it may be said that there are two distinct methods of apportioning the amount to be paid by the private property; viz.: (1) according to the frontage, and (2) according to the area.

647. Frontage Rule. By far the more common method of apportioning the assessments is pro rata according to the frontage upon the improvement. This method is often designated as the front-foot rule. Of the forty-five cities in Table 36, page 328, which assess the private property for street improvements, thirty-eight or 84 per cent follow the frontage rule, three use a combination of frontage and area, one uses area alone, one value alone, and in two of the cities the method employed is left to the judgment of the assessing board.

Ordinarily the frontage is an equitable basis upon which to distribute the cost; but under some circumstances a rigid apportionment according to frontage gives anomalous results. For example, if most of the lots have their shorter side on the improvement and one has its longer side thus placed, the frontage rule will give inequality—particularly if the latter lot is very narrow. This condition frequently occurs—for example where the most of the lots front upon the street to be paved, while some front upon an intersecting street. In this case, it is customary to extend the assessment to the middle of the block; that is, assess the lots between the pavement and the center of the block, in which case it becomes a difficult matter to determine the equitable portion for each of these lots. A rigid adherence to the frontage rule sometimes works injustice near the intersection of two streets cutting each other at an acute angle. However, no method can be devised that may not require modification to fit unusual conditions.

648. Area Rule. In a few cities, 7 per cent of those in Table 36, page 328, the cost of street improvement is distributed in proportion to the area of the abutting lots; but usually the area is used in combination with the frontage. Thus in Brooklyn, N. Y., 60 per cent of the cost is distributed in proportion to the frontage and 40 per cent according to the area. An amendment to the charter of St. Louis proposes to charge 25 per cent of the cost of the pavement according to the frontage and 75 per cent according to the area. The area rule finds its greatest justification on curved streets.

649. Corner lots are usually the cause of irritation and objection under either the frontage or the area rule, and the method of assessing them differs materially in different cities. In some cases each margin is considered a front on its proper street, without any modi-

ification in the rate of assessment; in a few cases under the area rule, an additional per cent is imposed upon the corner lot for the pavement of either street; but usually the corner is assessed according to frontage at a less pro rata than the inside lots, since it may be assessed on both streets.

650. Terms of Payment. There are various methods of paying the assessment. 1. The entire amount may become a lien upon the property as soon as the work is completed, to be collected (*a*) by the contractor, or (*b*) by the city acting only as collecting agent for the contractor, or (*c*) by the city, which also becomes responsible to the contractor for the payment of the money. 2. The amount may be divided into equal annual installments, usually five or ten, with interest on deferred payments, to be collected (*a*) by the contractor, or (*b*) by the city, the contractor receiving special paving-district bonds, or (*c*) by the city, the contractor receiving general city-bonds. 3. The city may raise a paving fund by general tax or by selling bonds, and pay for improvements as made independent of the collection of the special assessments. The second method is the more common. The first is objectionable because the amount becomes immediately due; and the third is objectionable on account of the difficulty of making the assessments and collections keep pace with each other, and also because of a tendency to produce extravagance.

651. Legality of Levy. Special assessments can be levied only under explicit authority of the law. The different states have very complete and explicit statutes governing special assessments; and the courts always hold that any material departure from the prescribed procedure invalidates the assessment.

652. GUARANTEEING PAVEMENTS. It is a common custom to require the contractor to guarantee the pavement for a term of years, which guarantee is supported either by an indemnifying bond or by a portion of the cost of the pavement retained by the municipality until the expiration of the specified period. In some cases the guarantee is an agreement that if time shall reveal that the materials or the method of construction are not according to the contract, the contractor shall make the defect good; but in other cases, the so-called guarantee is virtually a contract to maintain the pavement for the specified period and to turn it over in good condition at the end of that time.

Apparently the guarantee originated in this country with the introduction of sheet asphalt pavements. The material was new,

the method of laying it was untried, and hence no city would run the risk of paying for an unknown and uncertain pavement; consequently the contractor agreed to guarantee the pavement for a period of years. At present most cities continue to exact a guarantee for asphalt pavement, ranging from five to fifteen years, on the ground that the method of testing the material and the manner of laying it are too little understood by engineers to insure good and durable work without a guarantee. At the beginning of the use of brick as a paving material a guarantee was sometimes demanded; but at present it is as a rule not required with this material.

653. The requirement of a guarantee of the pavement is justifiable when the material to be used is new and there is little or no opportunity for the engineering department to acquire the knowledge necessary for an effective inspection of the work; but as a rule a guarantee, particularly for a long time, is unwise for the following reasons: 1. The contractor has no control over the street after the pavement is completed; and it is difficult to discriminate between defects due to improper material and the effects of ordinary wear, which may differ materially on different streets. It is also difficult to discriminate between defective workmanship and damages due to causes for which the contractor is in nowise responsible, as, for example, fires, escape of illuminating gas, settlement of trenches made after the completion of the pavement, etc. 2. It is difficult to enforce the guarantee clause if, on the one hand, the engineering department inspects the material and accepts the workmanship; and, on the other hand, if a representative of the city does not inspect the work there is liability that the streets may be needlessly obstructed and the public greatly inconvenienced by a bungling experiment by the contractor. The difficulty of enforcing a guarantee is much less in a large city where there is more work to be had and where the contractor desires to protect his reputation with a view to securing contracts in the future, than in a small city having but little work; and the difficulty is still further increased if the law requires that the contract shall be let to the lowest responsible bidder—as is usually the case.

The contractor objects to the guarantee, not without justice, on the following grounds: 1. The specifications are prepared by the engineering department of the city, and as the quality of the material and the method of construction is prescribed by the city and subject to the approval of its representatives, the contractor should not be held responsible for the result. However, the suffi-

cient answer to this objection is that the contractor accepts the specifications when he enters into contract, and is therefore rightfully bound by them. 2. The expense is needless and excessive, whether an indemnifying bond is required or a per cent of the contract price is retained, which expense in the long run adds to the cost of the pavement. It is more expensive to the contractor if the city retains a per cent of the contract price, since a portion of his capital is then tied up, which in turn drives out the small contractor, decreases competition, and tends to increase the cost of the pavement. On the other hand, the interests paying for the pavement are better protected if the city retains a per cent than if an indemnifying bond is accepted, since in the former case the city has the money in hand with which to make the needed repairs in case the contractor fails to do so; but the proper care of such deferred payments adds materially to the labor and responsibility of municipal administration.

The contributing property holders and citizens favor the guarantee as a defense against incompetent or dishonest city officials and employees. The guarantee is also sometimes defended on the ground that it is the cheapest method of securing good work, since it is impossible at reasonable cost for the engineering department to inspect all stages of the preparation of the material or to acquire the knowledge necessary for an effective supervision of the construction; but in general this claim is not true. It is neither creditable to the engineering profession nor economical to the municipalities to leave all exact knowledge of paving matters in the hands of the paving contractors.

654. The proper length of the guarantee period is a matter about which there is considerable difference of opinion. For asphalt pavement a guarantee for five years is quite common, although sometimes a fifteen-year guarantee is required. With stone block, brick and most other forms of pavements nine months, or at most a year, is sufficient to reveal any serious defect of material or workmanship, and therefore a long guarantee is not necessary.

655. Maintenance by Contract. As stated above it is common to require a so-called guarantee which is virtually a contract for maintenance for the specified period. Maintenance by contract is justifiable if the engineering department of the city does not possess, or can not reasonably be expected to obtain, the information necessary in repairing the pavement; but as a rule maintenance by contract is undesirable, for four reasons: 1. The contractor has no con-

trol over the streets, and the repairs required are dependent upon the restrictions against opening the pavements and also upon the regulations for keeping the streets clean. 2. It is difficult to specify beforehand the amount and the nature of the repairs that may be required by the ordinary use of the pavements, particularly as the opening of new streets or the paving of others may materially alter the amount or nature of the traffic on any particular pavement. 3. It is impossible to determine accurately the condition of the pavement at the end of the contract period. 4. With a new and untried material it is impossible to determine what is a reasonable expense for maintenance.

A contract for maintenance is sometimes defended by the property holders on the ground that thereby some one is secured who is admittedly responsible for the condition of the pavement and who is more amenable for neglect than are city officials. However, if the city officials can not be trusted to repair the pavements directly, it is doubtful whether they may reasonably be expected to supervise the repairs to be made by the contractor. The choice between maintenance by contract and by municipal authorities directly will usually depend upon the local conditions.

The pavements of Paris, France, were formerly maintained by contract, but are now maintained by the city directly.

656. Tearing up Pavements. The most serious cause of the destruction of pavements is the frequency with which they are torn up for the introduction or repair of underground pipes, conduits, etc. No pavement has been introduced, and probably none ever will be, which is not seriously injured by being torn up. With care and intelligence a pavement may be replaced in nearly its former condition; but it almost never is so replaced, and under the conditions which such work is done, it is almost impossible to get it so replaced. The only remedy for the frequent disturbance of pavements is the construction of a subway in which to place pipes, wires, etc.; but it is doubtful if any such remedy would be lasting for the streets are continually being put to new uses. Formerly it was thought sufficient to provide for water and gas pipes and sewers; while now conduits are required for telegraph, telephone, and electric light wires; and street-car tracks are constructed on the surface, above the surface, and below the surface; and in some cities space is required for pneumatic tubes, and pipes for distributing heat, compressed air, cold and hot water, etc.

The only thing that can be done is to reduce the opening of the

pavements absolutely to a minimum, and then to take the utmost care to see that as little damage as possible is done in making the opening and that the pavement is restored in the best way possible. A few years ago in New York City a quarter of a mile of trench was opened for each mile of pavement, and in addition there was an opening for each 35 linear feet of street. The year stated was about an average for those immediately before and after. In Chicago in 1902 200,000 square yards of pavements were taken up by public service companies, which is equal to about 10 miles of pavement 36 feet wide; or in other words, the equivalent of one sixth of all the new pavements laid in the city in that year was torn up by the public utilities corporations. This did not include the pavements taken up by the city itself to lay water pipes, sewers, etc.

The amount of money spent in digging up the streets is a considerable item, not counting the interference with travel and business; but the expense, being distributed among various interests, is not usually sufficient to cause any one company to re-construct its system. It is probable that the interests of the public are frequently sacrificed to the interests of the private companies using the streets—usually without paying for the privilege.

Under the best municipal administrations of Europe neither corporations nor individuals are permitted to disturb the pavements. All removals and restorations are done by the city's own employees, upon the deposit, by the parties who require the streets to be opened, of a sufficient sum to cover the expense of each piece of paving done, at a fixed price per yard according to the kind of pavement. Moreover, interference with the pavements is of rare occurrence, for the companies having pipes underground are require thoroughly to examine and reinstate their mains and services concurrently with the paving of a street, due notice of the execution of which is given by the city.

657. Nearly all cities have ordinances governing the opening of pavements, which differ greatly in character and severity; but generally the result is unsatisfactory owing to the real difficulties of the case, or to inefficient administration, or to unexpected emergencies. There is also great variation as to the method of doing the backfilling, replacing the foundation, and re-laying the pavement, and also as to who shall do the work,—whether city departments, private parties, public utility company, or contractor; and again none is satisfactory. This is a serious unsolved problem in American municipal administration.

CHAPTER XII

STREET DESIGN

660. From the point of view of future needs—commercial, sanitary, and esthetic,—it is unfortunate that cities grow up by successive additions under the stimulus of private greed and real estate speculation, without any comprehensive or well considered street plan. In some instances—notably Paris, London, and Boston,—vast sums have been spent to correct what might have been prevented in the original plan of the streets.* In most cities transformation—slow and expensive, if it comes at all—is the only remedy; but a mended article is never as good as one originally well made.†

Unfortunately there are few cities in this country having adequate regulations governing suburban development. Municipal authorities should regulate the street plan of subdivisions and additions so as to secure a harmonious whole, and particularly with a view of making the streets continuous and to afford suitable channels of communication. Where such regulations do not exist, streets will be laid out in such a way as best to develop the particular property, regardless of the interests of the public. Washington City, which has the best street plan of any American city, has been disfigured by ill-planned additions, although at present stringent rules govern the width and the arrangement of the streets of additions and subdivisions.

661. STREET PLAN. Since an engineer is occasionally called upon to plan a city, and often to lay out additions to cities and villages, the various street plans for a city will be considered. In planning the streets of a city three objects should be kept in mind;

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* For example, Paris spent $14,000,000 in improving the Rue de Rivoli, and London $33,000,000 on the Strand Improvement.

† For an elaborate and abundantly illustrated treatise from the view point of an engineer, of many of the things considered in this chapter, see The Planning of the Modern City, Nelson P. Lewis; John Wiley & Sons, New York, 1916.

viz.: (1) the subdivision of the area in such a manner as to give the maximum efficiency for business or residence purposes; (2) sufficient accommodation for the pedestrian and vehicle travel on the streets; (3) good drainage; and (4) easy communication between the different parts of the city.

662. Size of Lots. Owners in subdividing property are anxious to make as many lots as possible; and in some other respects small lots are to be preferred. It is desirable to make the lots of such a size that few of them will be subdivided, as clearness of identity in transferring or assessing the lot is maintained by always referring to the original number. A frontage of 25 feet seems the best. This width is suitable for business purposes, and for residence streets two or more lots will give proper grounds. Business lots are sometimes made only 18 or 20 feet wide, but 25 feet is by far the more common.

Lots are seldom less than 100, nor more than 180, feet deep; and usually vary from 100 to 150 feet. A lot more than 150 feet deep is objectionable, because of the temptation to build unsightly residences fronting on the alley and because of the usual indifference to keeping a deep lot in good sanitary condition.

663. Size of Blocks. With a rectangular system of streets, the blocks are preferably long and narrow; since the distance required between streets in one direction is only that necessary to give the proper depth of lots, while in the other direction the streets need be only close enough to provide convenient channels for the traffic.

For convenience, especially in business districts, it is best to have an alley run lengthwise through the block. The alley varies from 10 to 30 feet, but is usually from 16 to 20 feet.

The above depth of lot and width of alley makes the width of the block 220 to 330 feet. The length of the block will depend upon the requirements for traffic perpendicular to the principal streets. Sizes of blocks vary much in any particular city, and still more between different cities. The following are the dimensions of typical blocks in several cities: Boston, 220×400 feet, and 100×550 feet; New York, 200×900 feet, and 200×400 feet; Philadelphia, 400×550 feet, and 500×800 feet; Washington, 400×600 feet, and 300×800 feet; Montreal, 250×750 feet; Chicago, 300×350 feet, and 300×500 feet.

Fig. 103, page 338, illustrates the advantages to be derived from a careful study of the best size of blocks and of the most advan-

tageous arrangement of streets. The left-hand side of the diagram shows the typical arrangement of streets and blocks in the residence district of New York City, the shaded portions representing the usual buildings. The right-hand side shows a much superior arrangement.* The three center blocks of the present plan comprise an area of 720×800 feet, and contain 480,000 square feet of building area and 96,000 square feet of streets, and in the corresponding area of the proposed plan, there are 481,000 square feet of building area

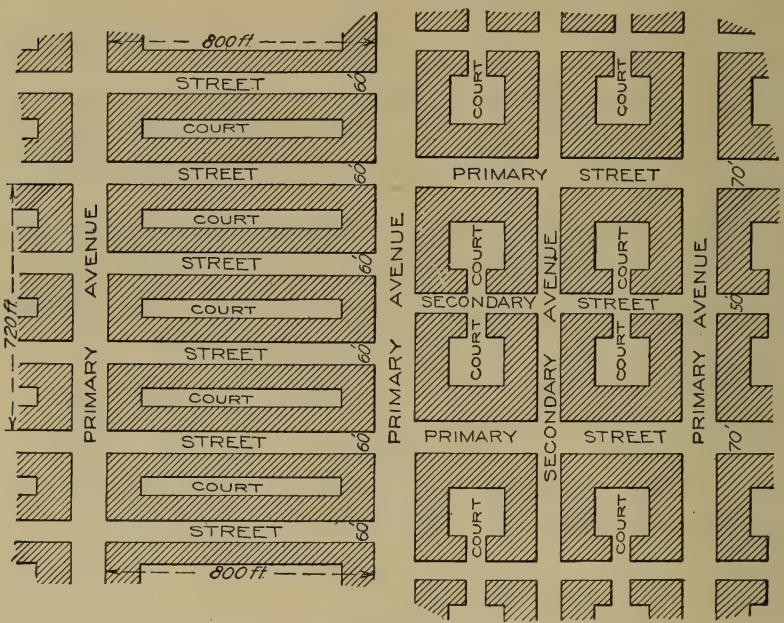

FIG. 103.—IMPROVED ARRANGEMENT OF STREETS AND BLOCKS.

and 94,200 square feet of streets; therefore the two plans give substantially the same area for buildings and for streets. In the first case the length of streets is 1600 feet, in the second 1520 feet; therefore the two plans have practically equal light and air. The proposed arrangement is the better in the following particulars: 1, number of corner sites; 2, accessibility of rear entrances for delivery of provisions, coal, etc., and the removal of garbage, ashes, etc., and in case of fire; 3, removal from the street of dangerous and cramped

* Proposed by Mr. J. F. Harder, in Municipal Affairs, Vol. 2, p. 41–44. Reform Club, New York City, 1898.

cellar entrances; 4, removal from the main or primary streets of the loading and unloading of trucks; and 5, increased transportation facilities in a direction perpendicular to the length of the original blocks.

664. Location of Streets. In planning a system of streets there are two objects that should be carefully considered, viz.: the drainage and easy communication between the different sections of the city. Not infrequently these elements have been overlooked or neglected. The surface drainage, the sewerage and the travel must follow the general slope of the land; and therefore if there is much irregularity of contour in the site, a location of the streets with reference to the contours will afford at once the best drainage and the easiest communication between different parts of the city. If the site is nearly level, the relationship between the slope of the land and the direction of the streets is comparatively unimportant; but the arrangement of the street plan to afford the greatest facilities for communication between the different parts of the city is still an important matter. Therefore the conclusion is that on a site of irregular contour the streets should be located with reference chiefly to the topography, and on a level site primarily to secure the most direct and easiest intercommunication.

665. *Location with Reference to Topography.* Unfortunately in this country our very desirable rectangular system of public land survey has frequently led to the adoption of a very undesirable rectangular system of streets which, though convenient for dividing property into the greatest number of rectangular lots upon which can be built the greatest number of rectangular buildings, has little else to recommend it. Surface drainage sewerage and travel should follow the slope of the country, and any attempt to deviate from this becomes a serious question in the building of a city upon any but nearly level ground. The streets are of necessity the drainage lines of the city and should be placed in the natural valleys, and the failure so to locate the streets in many cities where the land is very irregular in contour has led to great expense in the construction of the streets and of a system of storm-water sewers.

The upper half of Fig. 104, page 340, shows an actual case of a system of rectangular streets located without any reference to the topography; and the lower half of the same diagram shows a proposed arrangement * that would save much expense in grading the

* By W. D. Elder in Proc. Michigan Engineering Society, 1898, p. 52.

streets and at the same time give a quick entrance into the center of the city, and also give long easy grades from the heart of the city to the higher outlying district.

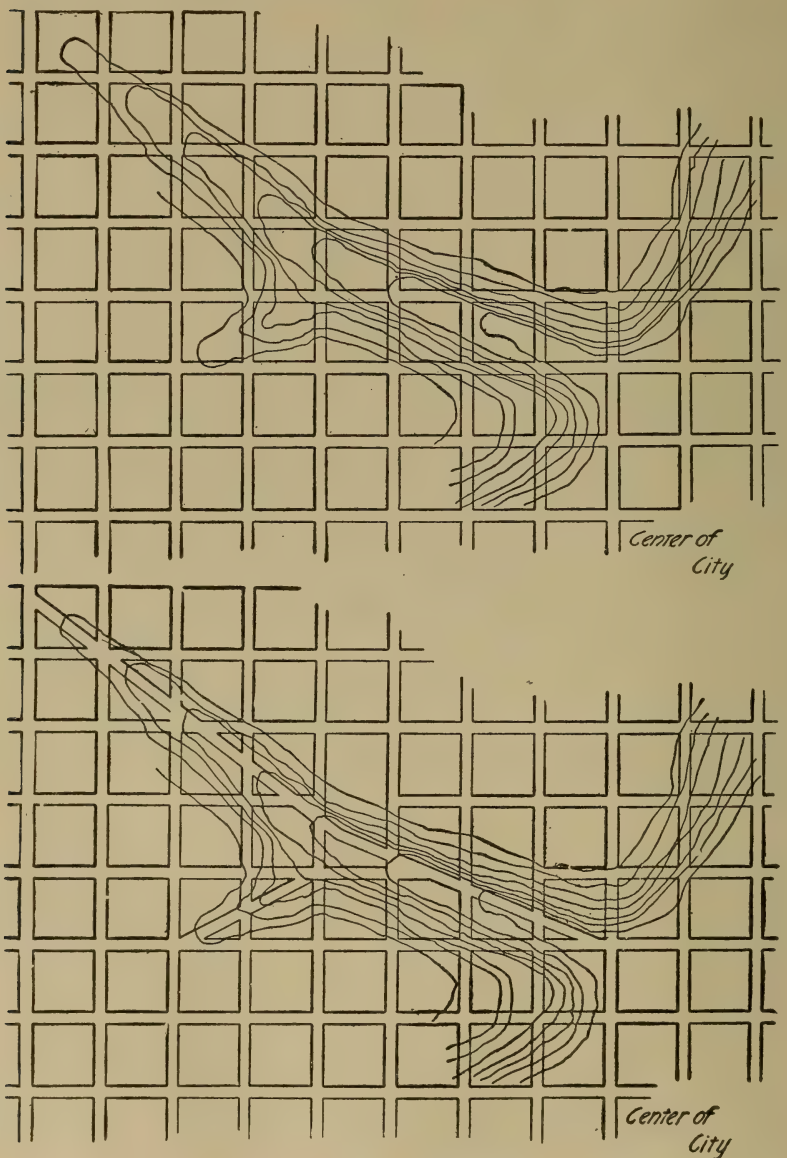

FIG. 104.—LOCATION OF STREETS WITH REFERENCE TO CONTOURS.

666. The original rectangular street system of San Francisco was laid out without much attention to the resulting street grades, some of which are 55 per cent. As rapidly as possible these excessive grades are being reduced. Recently $30,000 was spent to reduce the grade from 29 to 16 per cent through one block. The cost was something like 15 per cent of the value of the abutting property. This extreme case involved several unique but expensive features.*

667. *Location with Reference to Directness of Communication.* There are three distinct general plans for city streets with reference to directness and ease of communication.

668. One consists of a system of parallel streets crossing a similar system at right angles. This is often called the checker-board system, but more properly the rectangular system, since the blocks are not necessarily squares. This arrangement gives the maximum area for blocks, and also furnishes blocks of the best form for subdivision into lots. The rectangular system is the most common, and has its most marked exemplification in Philadelphia.

669. A second arrangement of streets consists of the rectangular system with occasional diagonal streets along the lines of maximum travel. This system was employed by L'Enfant in planning the city of Washington. Fig. 105, page 342, shows a portion of that city. To a limited degree, the same plan was adopted in laying out the city of Indianapolis, which has four broad diagonal avenues converging to a circular park in the center. These two are the only cities of any importance in which this system was adopted in advance of building. This system is usually, but somewhat improperly, called the diagonal system.

The chief advantage of the diagonal street is the economy due to the saving of distance by traversing the hypothenuse instead of the two sides of a right triangle. In Rome, London, Paris, and in numerous other smaller places in Europe, whole districts have been razed to make way for new streets to serve as arteries for increased traffic.

A second, and by no means an unimportant, advantage of the combination of the diagonal and the rectangular system is the open squares and spaces so grateful to the eye and of no little sanitary value in compactly built cities. New York City has recently been spending a million dollars a year to create such spaces by purchasing land and demolishing the buildings.

* *Engineering News*, Vol. 75 (1916), p. 12–13.

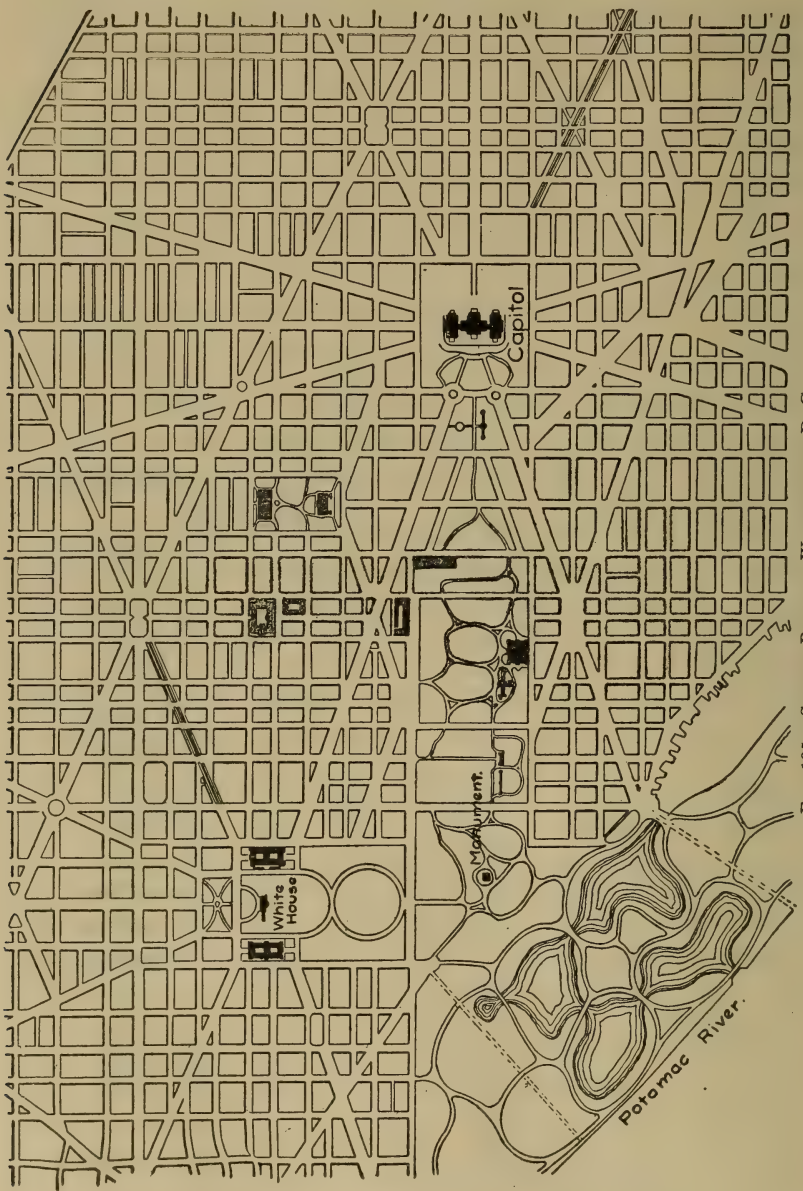

FIG. 105.—STREET PLAN OF WASHINGTON, D. C.

Although the diagonal avenue occupies ground that might otherwise be used for building purposes, there is a compensating advantage in the greater length of street front obtained.* In many cases the total cost of cutting diagonal streets through built-up districts has been paid by the increased value of the property on and near the street thus opened up.

670. The third arrangement of city streets is the ring or concentric plan, which is very popular in Europe. The most noted example is Vienna with its Ring-strasse (ring street) within and its Gürtel-strasse (girdle street) without. The former is 187 feet wide and encircles the public buildings and the leading houses of business and amusement. The enclosed network of streets intersect the Ring-strasse at forty points, and outward from it extend fifteen main radial avenues.

671. WIDTH OF STREETS. The width of city streets is important on account of its influence upon the ease with which traffic may be conducted and also because of its effect upon the health and comfort of the people by determining the amount of light and air which may penetrate into thickly built-up districts. The streets of nearly all large cities are too narrow, being crowded and dark. A more liberal policy in planning streets would probably be of pecuniary advantage, since there is usually an enhanced financial value due to wide streets. A lot 100 feet deep on a street 80 feet wide is usually more valuable than a lot 110 feet deep on a street 60 feet wide; that is to say, within reasonable limits land is usually more valuable in the street than on the rear of the lot. Wide streets are especially needed where they are bordered by high buildings or are to carry street-railway lines.†

In order properly to accommodate the traffic in business districts of cities of considerable size, a street should have a width of 100 to 140 feet, the whole of it being used for roadway and sidewalks; while residence streets in a city of considerable size, where the houses are set out to the property line and stand close together should have a width of 60 to 80 feet. Although it is advantageous to have a wide street, it is not necessary, nor even desirable that the whole width be paved; the central portion may be paved, a

* For a discussion of this phase of the subject, see an article by L. M. Haupt in Jour. Franklin Inst., Vol. 103, p. 252.

† For an elaborate and instructive article on this subject see a paper by John Nolen before the 1911 National Conference on City Planning, *Engineering and Contracting*, Vol. 35 (1911), p. 621–622.

strip on either side being reserved for grass plats. The width of the pavement should be adjusted to the amount of travel, which varies greatly accordingly as the street is a business street, a thoroughfare, or an unfrequented residence street.

The width of the streets in different cities varies greatly. In the older places in New England and the Central States, many of the streets are only 30 to 40 feet wide; but in the West a street is seldom less than 60 to 66 feet wide. In both regions the principal streets are often 80 to 100 feet wide, and in many of the larger cities the boulevards and great avenues are 150 to 180 feet. The main avenues in Washington are 160 feet wide, in New York 135, and in Boston, 180 feet.

At present the regulations governing the width and the arrangements of additions and subdivisions of Washington, a city which has the best street plan of any in America (see § 669) are: "No new street can be located less than 90 feet in width, and the leading avenues must be at least 120 feet wide. Intermediate streets 60 feet wide, called places, are allowed within blocks; but full-width streets must be located not more than 600 feet apart."

672. Area of Streets. The proportion of the area of the city devoted to streets varies greatly, particularly between the older and the newer cities. The following is the per cent of street area in a few extreme cases of American cities: *

Minimum Street Area		Maximum Street Area	
1. Taunton, Mass.	3.20 per cent	Duluth, Minn.	86.7 per cent
2. Worcester, Mass.	5.43 " "	Dallas, Tex.	78.3 " "
3. Binghamton, N. Y.	7.55 " "	Denver, Colo.	73.9 " "
4. Philadelphia, Pa.	8.42 " "	Indianapolis, Ind.	56.4 " "
5. Boston, Mass.	8.76 " "	Washington, D. C.	43.5 " "
6. Lowell, Mass.	8.92 " "	Davenport, Ia.	42.1 " "
7. Fall River, Mass.	9.17 " "	Evansville, Ind.	40.8 " "

The area devoted to streets and alleys in a few of the principal cities of the world is as follows:

Area of Streets and Alleys	
1. Washington	54 per cent
2. Vienna	35 " "
3. New York City	35 " "
4. Philadelphia	29 " "
5. Boston	26 " "
6. Berlin	26 " "
7. Paris	25 " "

* Census Bulletin No. 100—July 22, 1891,—p. 16.

673. Width of Pavements. It is wise to make the streets of residence districts of liberal width for sanitary and esthetic reasons; and also because the future of the street can not be certainly foreseen,—the residence street may become a business street, or an unfrequented street a thoroughfare. However, it is not necessary that the whole width should be devoted to wheelways and sidewalks, particularly in small cities. A grass plat between the sidewalk and the pavement, in which shade trees are set (§ 696), adds to the beauty of the street and to the comfort of the residents by removing the houses farther from the noise and dust of the pavement. The grass plat or parking also affords an excellent place in which to place water and gas pipes, telephone and electric-light conduits, etc. In large cities where the street front is built up solid with houses of several stories, it may be necessary to dispense with the grass plat, and to devote the entire street to sidewalks and roadway.

It is universally admitted that pavements are desirable; but often, owing to the unwillingness of at least some of the people to pay for them, it is difficult to secure them. Except for the cost, the wider the pavement the better; but length is more valuable than width. An excessive width is a needless expense, and delays or prevents the getting of any pavement at all; hence one help toward securing pavements is to make the pavement only wide enough to accommodate the traffic. Not infrequently the pavements of suburban and residence streets are needlessly wide. A narrow pavement not only costs less to construct, but also costs less to clean and maintain; while the cost of maintenance depends chiefly (or, with a pavement not subject to natural decay, wholly) upon the amount of traffic, and hence is nearly (or entirely) independent of the width.

674. Without Car Track. A width of 18 feet affords sufficient room for a vehicle to pass when another is standing on each side of the pavement—a rare occurrence;—and therefore it appears that a pavement 18 feet wide is sufficient for the less frequented residence streets. The only objection to a very narrow pavement is the difficulty of turning a vehicle in such a street. The seriousness of this objection depends upon the construction of the vehicle. Many delivery wagons, express wagons, etc., may be turned on an 18-foot pavement. If occasionally a vehicle is compelled to go to the corner turn, to or even to drive around the block, the inconvenience is not very serious, and is so infrequent as not to justify

any considerable expense to prevent it. A width of 20 to 24 feet is probably sufficient for a majority of residence and suburban streets. When a residence street is an artery of travel, it may be necessary to make the pavement wider than stated above. In a number of cities, there has been a marked tendency in recent years to reduce the width of pavements on residence streets.

Thirty feet affords sufficient room for two vehicles to pass each other where two others are standing at the curb; and therefore this width of pavement is ample for business streets in small places. On a narrow business street it may be necessary to curtail the width of the pavement to prevent the sidewalk space from being unduly encroached upon.

In many of the cities the width of the pavement is uniformly a fractional part of the total width of the street, regardless of the needs of traffic. In many cities, both American and European, the pavement is three fifths or 60 per cent of the width of the street. In New York City and Brooklyn the rule seems to be to make the pavement half the width of the street. In Washington City there is no hard-and-fast rule, but the following is the usual relation: on streets 60 feet wide or less, the pavement is 25 feet or 40 per cent of the width of the street; on streets from 60 to 90 feet wide, the pavement is 25 to 35 feet, or 40 per cent; and for streets 130 to 160 feet wide, the pavement is 40 to 50 feet, or 30 per cent.

675. With Car Track. For a residence street containing a car track, the minimum width permissible is 28 feet, which will allow a car to pass with a vehicle on each side of the track. In Brooklyn a great many streets only 34 feet wide between curbs contain a double line of street-car tracks, which leaves a space of only $9\frac{1}{2}$ feet between the track and the curb. This is astonishingly small, but seems to do fairly well.

On a business street containing a car track, it is wise to make the pavement wide enough to permit a vehicle to pass between the car and another vehicle standing at the curb. This will require about 48 feet. If the street is too narrow to permit this width of pavement and also the proper width of sidewalks, only one track should be allowed in the street; if a double track is necessary the cars should be required to make the return trip by another street.

At Rochester, N. Y., the car tracks on residence streets are located on the parking at the side of the street. This is an unusual arrangement, but it possesses some advantages. 1. It separates

the vehicle and car traffic, and prevents mutual interference. 2. It permits a narrower pavement. 3. It prevents disturbance of the pavement to repair the car track. 4. It lessens the danger of a passenger's being struck by another car or a vehicle in leaving a car. The objection to this arrangement is that it interferes with the grade of the driveways to private grounds.

676. STREET GRADES. The fixing of street grades is one of the most important functions of municipal engineering, since the grade system of the streets is the foundation of all municipal engineering matters. The grades should be established before the sewer system is planned; and if they are established before the property is improved the problem is comparatively simple, since they may be laid chiefly with reference to obtaining within proper limits of cost desirable gradients for the street. But when buildings have been erected, sidewalks constructed and trees planted, it is often extremely difficult to secure grades which will harmonize the various and conflicting interests.

677. Elements Governing Grades. The grades necessarily depend mainly upon the topography of the site; but in general the determination of the proper grade for a street requires the consideration of the following elements: (1) the drainage, (2) the cost of earthwork, (3) the accommodation of travel, (4) the effect upon the abutting property, and (5) the general appearance of the street.

678. *Drainage.* The streets are the natural drainage channels of the city; the lots must drain into them, and the house must drain into the sewers placed in the streets. When no storm-water sewers are to be constructed, the grades become very important, since the streets must provide for the surface drainage of the city, and particular consideration must be given to relative grades and gutter capacities in order to prevent the excessive concentration of storm water at the lower levels and to provide for its proper distribution and disposal.

679. *Cost of Earthwork.* Not infrequently the cost of making the excavations and embankments is given undue weight. The balancing of cuts and fills is often properly a controlling element in country road construction, but it should have relatively little weight in determining the grades of city streets. The expense for earthwork is incurred once for all, and a few hundred dollars more or less is usually unimportant in comparison with the expense of maintaining the street surface and the drainage system, and

the cost of conducting traffic over the grades, and also in comparison with a better general appearance of the street.

680. *Accommodation of Travel.* The question often is whether or not to secure ease of traction at the expense of increased cost of construction. The discussion in Chapter II, § 65–86, sheds a little light and only a little, as to the proper method of answering this question. Apparently engineers are inclined to overestimate the disadvantage to travel of a slight grade. Practical experience has demonstrated that there is not much difference in effect upon the cost of transportation between level roads and those having grades of 2 or 3 per cent unless such grades are very long or have an unusually smooth surface.

681. *Effect upon Abutting Property.* The private interests of the property holder should be carefully considered; although it is frequently impossible to establish proper grades without injury to the adjoining property. The general question is how far private interests should be sacrificed to the general good. It is better that the city or the other residents on the street should pay the owner damages than that lasting detriment should be done to the appearance of the street or to the traffic.

682. *General Appearance.* Some attention should be paid to the appearance of a longitudinal view of the pavement. It is desirable that the longitudinal grade be not changed so frequently as to give the street a wavy appearance. Further, the transverse grades at street intersections and on side hills should be so arranged as not to produce a confused appearance in looking along the street. The grades of the streets, both longitudinal and transverse, have a material effect upon the general appearance and beauty of the city.

683. Maximum Grade. In a general way the principles governing the determination of the permissible maximum grade of a city street are the same as for a country road, i. e., it is a question between the cost of operation on the one hand and the cost of construction and maintenance on the other, except that for a country road the cost of construction is chiefly the cost of moving the earth, while for a city street the cost of construction should also include the effect upon abutting property of high embankments or deep excavations, and except further that usually in the city heavy loads can take a circuitous route and avoid the maximum grade entirely. In determining the maximum grade for a street, the fact should not be overlooked that the smoother the pavement the more serious is a steep grade.

684. In the Borough of Manhattan, New York City, are some business streets having grades as steep as 6 per cent, and a number of residence streets have 10 per cent grades, and some have grades of 12, 15 and 18 per cent. Brooklyn, N. Y., has 4 per cent grades on business streets and 12 on residence ones. A number of cities have maximum grades on paved streets of 20 per cent—for example, Worcester, Mass., Syracuse, N. Y., Borough of Richmond, New York City, and Pittsburg, Pa. Burlington, Iowa, has an 80-foot street with a 24 per cent grade up which is laid a zigzag brick pavement 18 feet wide having a maximum grade of $14\frac{1}{2}$ per cent with a minimum radius of the inside curb of 16 feet. San Francisco has some extremely steep street grades, for one example see § 666.

For a discussion of the maximum grade for each kind of pavement, see the heading Maximum Grades in the chapter treating that particular pavement.

It is usually considered that a grade steeper than 15 per cent is impracticable and dangerous even for light traffic; and therefore if this grade can not be obtained, the street should be divided into two parts separated by a terrace or stone wall, each portion being entered only at its intersection with the cross street—see Fig. 118, page 358. A 10 per cent grade is usually considered prohibitive for heavy loads; and 5 or 6 per cent is considered the limit on business streets.

685. The selection of the proper pavement for the maximum grade is a matter of great importance. For the recommendations of a committee of the American Society of Civil Engineers concerning maximum permissible grades, see Table 15, page 57. It is usually held that sheet asphalt should not be laid on grades steeper than 2 to 3 per cent, although it has often been laid on 6 or 7 per cent grades, and in one instance on a 17 per cent grade (see § 887). Brick, or hard sandstone, or granite may be used upon the maximum grade. The sandstone and the granite blocks should be narrow and should be of a quality that does not wear smooth. It has been recommended to chamfer the corners of rectangular stone or wood blocks when laid upon steep grades, to give the horses a good foot-hold; but it is at least doubtful whether the benefit of a good footing is not neutralized by the increased tractive resistance. The joints should be filled with tar or hydraulic cement.

686. Minimum Grade. The street surface should have enough longitudinal slope to drain its surface well. With a smooth and

impenetrable pavement no ruts will be formed, and hence the determination of the minimum permissible grade is mainly a question of the grade of the gutter. If the drainage is carried away by underground storm-water sewers, the street may be perfectly level longitudinally, since the necessary grade for the gutters may be obtained by making them deeper as they approach the inlet to the sewer. For a further discussion of this phase of the subject, see Grade of Gutter—§ 711.

If it is inexpedient to vary the depth of the gutter (§ 710) or to increase the grade by constructing additional inlets and catch basins, it is necessary to secure the proper slope for the gutter by inserting a summit in the street solely for drainage purposes—usually referred to as an accommodation summit. However, it is undesirable that there should be frequent changes in the grade, as they give the pavement an unpleasant wavy appearance when one looks along the street.

687. Elevations at Street Intersections. One of the most important parts of the establishment of a system of street grades is the arrangement of the grades at street intersections. It is a common practice to establish only the elevation of the intersection of the center lines of the streets; but this often results in much confusion in determining the elevation for the curb at the corner, particularly where the two streets have considerably different grades. For example, in Fig. 106, assuming (for the present at least) that the curb is to be at the same elevation as the center of the street opposite, the elevation of the corner of the curb, *D*, as computed from the grade of *CB* is 90.20 feet; while the elevation of the same point as computed from the grade of *BA* is 91.20 feet—a difference of 1.0 foot. To obviate this source of confusion, the elevation of each corner of the curb and also of the intersections of the center lines should be established.

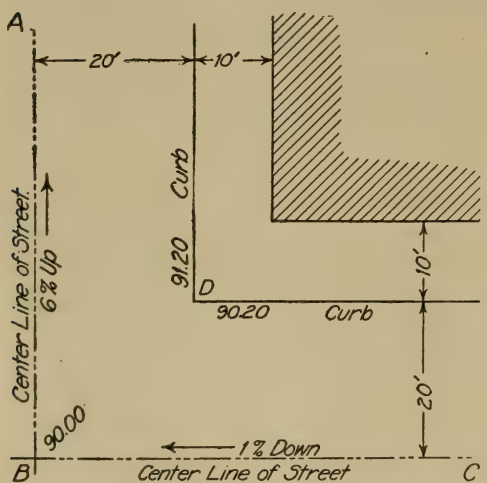

FIG. 106.—ELEVATION OF CURB AT CORNER.

A similar confusion occurs in attempting to compute the elevation of the corner of the property, from the grade of the corner of the curb. For example, in Fig. 107, assuming that the grade of the top of the curb is the same as that of the center of the street, and assuming that the sidewalk has a downward slope away from the property of 0.24 inch per foot (2 per cent), and also assuming that the grade of the corner of the curb, *D*, has been established as 80.00, then the elevation of the corner of the property, *G*, as computed from the grade of the curb *DE* is 80.30 feet, while the elevation of the same point computed from the grade of the curb *DF* is 80.80 feet.

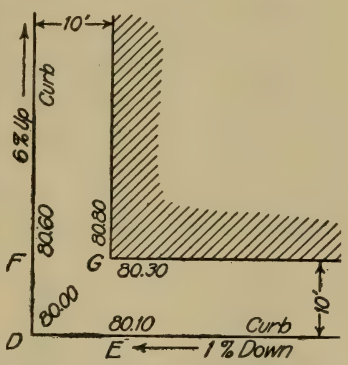

Fig. 107.—Elevation at Corner of Property.

Some engineers advocate establishing the elevation of the corner of the property and the determination of the grades of the curb and of the street therefrom; while others advocate establishing the elevation of the corner of the curb and from that determining the elevation of the corner of the property and also of the center of the street intersection. To be legal the elevation must be fixed by ordinance. The courts hold that the " elevation " is the top of the pavement in the center of the street; therefore it is necessary to establish by ordinance the elevation of the center of the street intersection. Further, to prevent misapprehension and error in computing the elevation of the corners of the curbs, and also to save the labor of computing them anew each time a lot is to be surveyed, it is wise to establish also the elevation of the corner of the curb. The ordinance should distinctly state the method to be employed in computing the auxiliary elevations of the sidewalk and of the corner of the property. Often the grades are established for only one street without due consideration of the intersecting street; and then when the second street is improved, the result is confusion, disputes, and sometimes suits for damages.

688. When the rate of grade of both streets is small, it is desirable that the entire street intersection from property line to property line should be level, a condition which permits the continuation of the section of each roadway until they intersect, makes the top of the curb at the four corners of the same elevation, and also allows the sidewalks at the corners to be level. That is to say, in Fig. 108,

the four points marked *b* and all the points marked *a* are in the same horizontal plane. Each street has its full crown on the line *bb*, and consequently there is a slight rise from *b* to *c*.

Where either or both streets have much inclination, it may not be wise to flatten out the intersection, and thereby increase the grade on the remainder of the street. Under these conditions, the best arrangement of the intersection is a matter requiring careful study and is one upon which there is much diversity of opinion. If steep grades are continued across intersections, they introduce side slopes in the streets thus crossed, which are troublesome and possibly dangerous—particularly to vehicles turning the upper corners. Such intersections are also objectionable on account of the difficulty of properly caring for the storm water. In residence districts it is usual to make the intersection "level from curb to curb"; that is, in Fig. 108, the four points marked *b* are in the same horizontal plane. The level places serve as breathing places, and lessen the danger of collision at the intersection. However, if the street has a considerable grade, a level intersection appears to have a decided pitch toward the hill, which gives the street an unpleasing appearance; and therefore under these conditions, it is better to apply, even in residence districts, the principle of the succeeding paragraph and give the intersection a moderate inclination down hill. If the intersection has only enough inclination to seem level, the general appearance of a series of such intersections is pleasing having the effect of a succession of terraces.

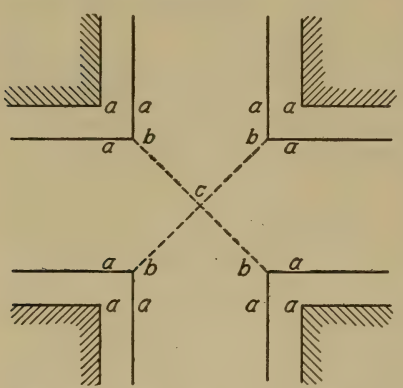

FIG. 108.—ELEVATIONS AT LEVEL STREET INTERSECTION.

The following rule * for adjusting the grades at street intersections is frequently employed and apparently is the most complete of any that has been proposed. "In the business section all the street grades of 3 per cent or less should be continued unbroken over the intersection; and streets having a steeper grade than 3

* Proposed by Messrs. Rudolf Hering and Andrew Rosewater for the streets of Duluth, Minn., in a report dated March 7, 1890. *Engineering News*, Vol. 25, p. 148–49; *Engineering Record*, Vol. 22, p. 53.

per cent should have an intersection of 3 per cent between curb lines. The grade of the curb between the other curb line and the property line should in no case be greater than 8 per cent. The elevation at the corner of the property should be determined by adding to each of the elevations of the curb opposite the corner, the rise of the sidewalk and taking the mean." Fig. 109 shows the elevations of a street intersection adjusted according to the above rules, assuming the transverse slope of the sidewalk to be 2 per cent (practically $\frac{1}{4}$ inch per foot—the usual value).

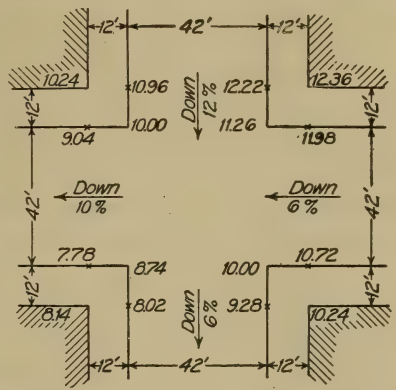

Fig. 109.—Elevations at Inclined Street Intersection.

The difficulty of adjusting elevations at an intersection is considerably increased if the two streets do not intersect at right angles. It is impossible to formulate any general rule, since each case must be decided according to the local conditions. Close observation and good judgment are required to secure a reasonably satisfactory adjustment.

689. Notice that if either street has a grade and is carried past the intersection nominally unchanged, the area between the four curb corners and that immediately adjacent will be a warped surface. For example, in Fig. 110, if the street S has a descent as indicated and the street W is level, and the unchanged crowns of the street intersect at C, the area marked w must be raised to carry the upper side of the street W over the intersection, and the portions marked v must be raised to carry the street S over the lower side of the street W. If the grade of either street is small this adjustment can be made by "warping in" or "boning in" the surface for a short distance.

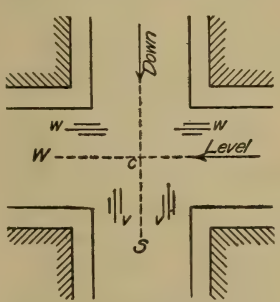

Fig. 110.—A Warped Street Intersection.

690. Vertical Curves at Grade Intersection. It is frequently claimed that the grade should be carried straight through from street intersection to street intersection, i. e., that the grade should not be broken in the block. Apparently the reason for this practice

is the claim that a break of grade between streets is unsightly. As usually put in, the angle of intersection is simply rounded off a little by eye; and if the change of grade is considerable, the appearance is not good. A change of grade in the block is nowise different from a change at the street intersection, except that the former is a little more conspicuous. For both appearance and the comfort of the travel, wherever there is considerable change of grade, the two grade lines should be connected by a vertical curve; and if this is properly done, a break of grade in the block or elsewhere is unobjectionable. A vertical curve should be inserted at a change of grade either of the pavement or of the curb.

By breaking grade in the block, it is possible to fit the grade line more closely to the natural surface, and thereby to decrease the cost of construction, to lessen the damage to abutting property, and to improve the general appearance of the street.

691. A parabola is the best form for a vertical curve and is most easily put in. In Fig. 111, AB and AC represent two grade

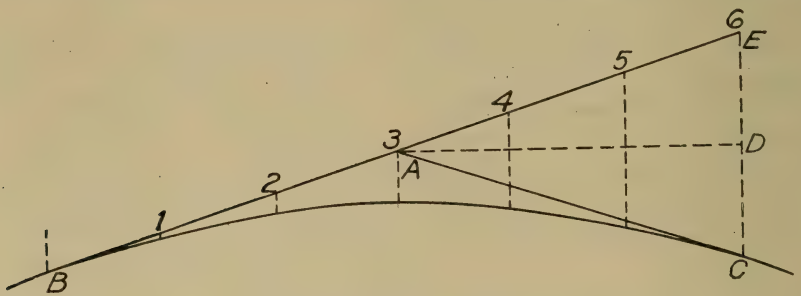

FIG. 111.—VERTICAL CURVE.

lines meeting in the apex A, joined by the vertical parabola $B\,C$, which is tangent to the straight grade line at B and C. The curve may be located by measuring ordinates vertically below the points 1, 2, 3, etc. The tangent distances $A\,B$ and $A\,C$ are equal. $D\,E$ is equal to the rise in half the length of the curve, i. e., from B to A; and $D\,C$ is equal to the fall in the second half, i. e., from A to C. If n represents the number of equidistant points to be established on the curve (including the second tangent point, C), then the ordinate at the first point $= x = \dfrac{D\,E + D\,C}{n^2}$. The ordinate at any other point is equal to x times the square of the number of equal divisions between B and that point; that is, the ordinate from 2 is $4x$, from 3 is $9x$, from 4 is $16x$, etc. In actual work, the

grade elevation of the points 1, 2, 3, etc., are to be worked out in the usual manner; from these elevations subtract the ordinates as computed above, and the remainder is the grade elevation of the respective points on the parabola $B\,C$. The agreement of the elevation of the last point on the curve, 6 in Fig. 111, with the point C on the tangent, checks the work of computing the elevations.

If the second tangent, $A\,C$, is level, $D\,C$ in the above value for x is 0; and if the second tangent has an up grade, $D\,C$ is minus, and the numerator $= D\,E - D\,C$. If the first tangent is level $D\,E = 0$; and if the first tangent has a down grade, $D\,E$ is minus, and the numerator $= D\,C - D\,E$. The principles deduced for Fig. 111 are equally true, if that diagram be turned upside down.

To secure the best results, there should be 15 feet of curve for each 1 per cent of change of grade, although 10 feet for each 1 per cent will give fair results. Long vertical curves make a graceful street. The effect of any proposed curve in lowering (or raising) the apex can be judged of beforehand by remembering that the distance from the apex A, Fig. 111, to the curve is equal to half of the difference in elevation between A and the mean of the elevations of B and C.

692. Crown of Pavement. The only reason for crowning a pavement, i. e., for making the center higher than the sides, is to afford surface drainage; and therefore the proper crown to be given to pavements will be considered under the head of Street Drainage —see Chapter XIII.

To make intelligible the discussion of the succeeding section, it is necessary to state here that in general the surface of the pavement consists either of two planes meeting at or near the center, or of a flat convex curve, usually the latter; and for present purposes it is sufficient to say that the average transverse slope is usually between 1 and 3 per cent (see § 720–24). The smoother the pavement and the better the construction, the less should be the crown.

693. Cross Section of Side-hill Streets. The arrangement of the cross section of a street upon a side hill is a matter requiring good judgment, that needless damage may not be done to the abutting property or that the general appearance of the street may not be uselessly sacrificed. In solving this problem no fixed rules can be laid down; but each case must be treated by itself, taking into account the local conditions. Fig. 112 shows the normal arrangement for a residence street on level ground; both footways are at the same elevation, the slope of the parking is the same on

the two sides, the tops of the curbs are at the same level, the gutters are of the same depth, and the surface of the street rises equally from each side to the center. The normal section for a business street

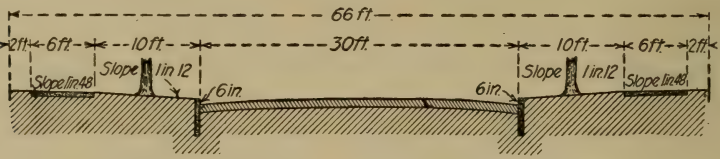

FIG. 112.—CROSS SECTION OF STREET ON LEVEL GROUND

would be the same except that the sidewalk would occupy all of the space between the curb and the building line. On a side-hill street the above conditions can not always be realized; and various expedients must be resorted to, depending upon the difference in elevation of the two sides of the street. The following are some of the common expedients.

1. If the difference is not very great, the curbs may be set at the same level, and one sidewalk may be placed higher than the other, the grade of the parking being different on the two sides. On a business street, where there is no parking, the slope of the footway may be different on the two sides. With sidewalks consisting of stone slabs, cement, or asphalt, a slope of at least $\frac{1}{8}$ of an inch per foot (1 in 96) is required for drainage; and a slope of more than $\frac{3}{8}$ of an inch per foot (1 in 32) is dangerous when covered with ice or snow.

2. A slight difference of level may be overcome by raising the curb, i. e., by increasing the depth of the gutter, on the high side, and lowering the curb on the low side, the crown of the pavement remaining symmetrical about the longitudinal center line. Fig. 113

FIG. 113.—CROSS SECTION OF SIDE-HILL STREET.

shows an actual section of a street arranged on this plan.* Except under extreme conditions, the curb should not show more than 10 inches because of the difficulty of stepping to or from the pavement, nor less than three inches because of the danger of its being overflowed when the gutter is full of melting snow.

* Trans. Amer. Soc. of Civil Engineers, Vol. 42, p. 5.

Sometimes a double curb is employed with a horizontal tread about 1 foot wide between the two risers. The combined concrete curb and gutter (§ 737) lends itself most readily to this form of construction. Fig. 114 shows such an arrangement.* The objec-

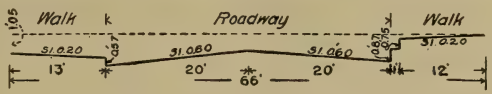

FIG. 114.—DOUBLE CURB FOR SIDE-HILL STREET.

tions to the double curb are: 1, its cost; 2, the difficulty of keeping the step neat and sanitary; and 3, it lessens the width available for roadway and sidewalk. In practice these objections have not proved to be serious. Instead of the double curb, it has been proposed to place the second step at the area line or property line, to which arrangement, particularly on a business street, the owner is liable to object.

3. A slight difference may also be overcome by making the upper side of the pavement nearly level and giving the lower half the normal slope.

4. The crown may be moved toward the high side of the street, the profile for each side being determined in the usual way; that is, the surface of the pavement may be two planes meeting at the

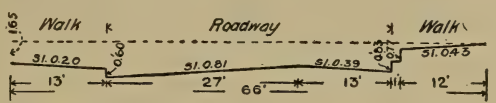

FIG. 115.—CROSS SECTION OF STREET ON A SIDE HILL.

crown with the intersection rounded off a little, or it may be two arcs of a circle or a parabola tangent to a horizontal line at the high point (see § 717 and § 718). Fig. 115 is an actual example of this method of solution.* If the longitudinal grade is consid-

FIG. 116.—CROSS SECTION OF STREET ON A SIDE HILL.

erable, as it usually is under such circumstances, there is no objection to the upper side of the street's being exactly level transversely. The extreme of this solution is to make the surface of the pavement a right line from the upper to the lower side—see Fig. 116.

* Trans. Amer. Soc. of Civil Engineers, Vol. 42, p. 5.

This arrangement has been objected to on account of its throwing all of the drainage to one side of the street; but this is not a serious objection, particularly if there is a considerable longitudinal grade, as usually there is.

5. Where there is a considerable difference of elevation on a residence street, it is sometimes wise to place the footway next to the curb, and to allow the slope of the parking to unite with that of the property—see Fig. 117.

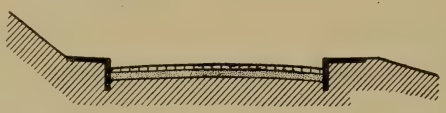

FIG. 117.—CROSS SECTION OF SIDE-HILL STREET.

6. When any or all of the above solutions fail, it may be necessary to terrace the street and to construct an upper and a lower roadway as shown in Fig. 118. For an example of the application of this method of treatment and some other interesting features, see § 666.

694. When the street contains one or more street-car tracks, the problem of arranging a cross section on the side of a hill is still more complicated. It is necessary that the two sides of a track shall be at least nearly on the same level; but it is not necessary that the two tracks shall be at the same elevation. A difference in elevation of $\frac{3}{4}$ of an inch between rails of the same track and of 3 inches between adjoining tracks is permissible.

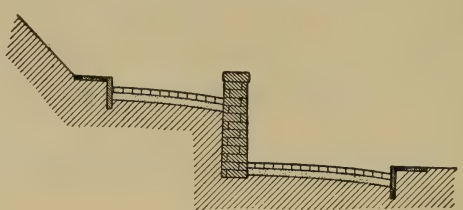

FIG. 118.—CROSS SECTION OF SIDE-HILL STREET.

696. STREET TREES. It is always desirable both for the shade and for the appearance to have residence streets lined with trees on each side. Although trees in the streets have an important sanitary and aesthetic value, opinions differ regarding the proper responsibility for them. One view vests all right and title to the tree in the owner of the property before which it stands; and the other asserts that the trees belong to the city at large, and that the individual

has no more right to the tree in front of his property than has any other citizen. In the first case, the planting of the tree, its kind, position, and care depend upon the public spirit of the property holder; and as a result the street presents a motley, straggling appearance often with no trees where they are most needed for the best general effect. Without some degree of public control, it is impossible even to approximate the best results of tree planting; but fortunately the number of cities in which the street trees are under the control of the municipal authorities is rapidly increasing.

In planning a system of streets, the location of the trees should be definitely provided for. They should be located in the grass plats between the sidewalk and the edge of the pavement, and at a sufficient distance from both the sidewalk and the pavement that there will be no danger of the roots lifting either. The trees should be spaced in the row so as to permit each when fully grown to spread to its natural dimensions, which usually requires a space, center to center, of 25 to 40 feet. Not infrequently trees are planted much too close—particularly in the fertile and originally treeless prairies of the Mississippi Valley;—and crowd each other and prevent a symmetrical growth. In planting trees, it is well to alternate those of rapid growth with those which mature more slowly; and then as the latter increase in size and demand more room, the former having served their temporary purpose, can be removed. Increased stateliness, impressiveness, and charm is secured if the trees, at least the permanent ones, on any one thoroughfare are of one variety. Different streets can have different kinds of trees, since in nearly all cities there is a large number of suitable varieties available.

697. In most states there are one or more cities that have obtained—either officially or by volunteer civic-improvement societies—valuable experience as to the varieties best suited to the environment, from whom data can doubtless be obtained by those desiring information concerning the kind of trees to plant in the streets of any particular city.

698. The following are the requirements for a street tree adopted by a commission of experts for Washington City.* "1. A somewhat compact stateliness and symmetry of growth, as distinguished from a low spreading or pendant form, so that the stem may reach a sufficient height to allow free circulation of air below the branches. 2. An ample supply of expansive foliage of bright early spring

* Proc. Amer. Soc. Municipal Improvements, Vol. 5, p. 97.

verdure, and rich in the variety of colors and tints assumed during autumn. 3. Healthiness, so far as being exempt from constitutional diseases, as well as from maladies frequently engendered by peculiarities of soil and atmosphere impurities. 4. Cleanliness, characterized by a persistency of foliage during the summer, freedom from falling flowers, and exemption from the attacks of noxious insects. 5. It should be easily transplanted, of moderately vigorous growth, and not inclined to throw up shoots from the root or lower portion of the stem. A tree of extremely rapid growth is generally short-lived. 6. The branches should be elastic rather than brittle, that they may withstand heavy storms; and lastly, there should be no offensive odor from foliage or flowers."

Of course, no tree planted amid the artificial conditions found in a large city will fully meet such rigid requirements. In 1872, at the commencement of systematic tree planting, the above commission recommended the following list of trees. The Silver Maple (Acer dasycarpum), the American Linden (Tilia americana), the European Sycamore Maple (Acer pseudo-platanus) and the American Elm (Ulmus americana) are thought to fill all the above requirements when not subjected to the attacks of insects. The Tulip Tree (Liriodendron tulipfera), Sugar Maple (Acer saccharinum), Sweet Gum (Liquidamber styraciflua), and the Red Maple (Acer rubrum) are the most beautiful of trees, their only drawback being that of not growing freely after transplanting. The Norway Maple (Acer platanoides), the Negundo (Acer negundo), and the American Ash (Fraximus americana) are recommended for certain places. The Button-woods or Planes (Platanus occidentalis and Platanus orientalis) are rapid growing, and for wide avenues are effective trees.

As a result of twenty-five years' experience, the trees are ranked as follows: " Silver Maple, Norway Maple, and Eastern Plane side by side in the first rank; then the Ginkgo, and Western Plane; and last American Linden, Oak, and Sugar Maple."

CHAPTER XIII

STREET DRAINAGE

701. The thorough drainage of a street involves four elements: (1) the surface drainage, (2) the gutters, (3) the catch basins, and (4) the underdrainage. They will be considered in the reverse order.

702. UNDERDRAINAGE. The underdrainage of a street is the first step toward paving it. Without thorough subdrainage a pavement is likely to settle here and there, forming unsightly depressions on the surface, and possibly breaking through. The subsoil may be drained by one or more lines of porous tile as described in § 114–24; but as a rule the surface and underground waters are both collected in the same drain, and therefore it is advisable to lay a line of tile at each side of the street or to construct a larger conduit under the center of the street. Since the pavement is practically impervious to water, a third line of tile under the middle of the pavement is unnecessary, however wet and retentive the soil originally.

If there is a grass plat between the pavement and sidewalk, as is usual on residence streets, the tile should be laid under the outer edge of the parking or grass plat; and if there is no parking, the tile should be laid under the gutter. The deeper the tile the better the drainage and the less the liability of its becoming choked with tree roots. The tile should not be too small since it is to carry both underground and surface water—the latter from a smooth and impervious pavement.

The formula for size of tile for the drainage of earth roads (§ 119) is worthless for pavements, since in cities a large proportion of the rain falls upon impervious roofs, pavements, sidewalks, etc., and nearly all speedily reaches the storm-water sewers. This subject has been very carefully studied in connection with the design of sewers, and the reader is referred to treatises on that subject, for further information concerning the size of drains or storm-water sewers required.

703. Catch Basins. The catch basin is a pit to receive the drainage from the surface of the street, in which is deposited the sand and other solid matter, and from which the water is discharged into the sewer or storm-water drain. A catch basin should fulfill the following conditions: (1) The inlet should offer the least possible obstruction to travel, should have sufficient capacity to pass speedily all the water reaching it, and should not easily be choked by leaves, paper, straw, etc. (2) The capacity below the outlet should be sufficient to retain all sand and road detritus, and thus prevent it from reaching the sewer; and will depend upon the area drained and the intervals between cleanings. (3) The water level should be low enough to prevent freezing. (4) The construction should be such that the pit may be easily cleaned out. (5) The pipe connecting the basin with the sewer should have sufficient capacity, and should be so constructed as to be easily freed of any obstruction. (6) It is desirable that the outlet should be trapped so as to prevent floating debris from reaching the sewer. (7) If the catch basin discharges into a sewer which also carries house sewage, the end of the outlet pipe should be trapped to prevent the escape of air from the sewer to the street through the catch basin.

704. The Construction. Catch basins are usually built of brick masonry, and plastered on the inside, at least up to the water line. Fig. 119, page 363, the standard of Champaign, Ill., is a good form. The opening of the inlet is protected by six half-inch iron rods. The several parts of the cast iron top are $\frac{3}{8}$ and $\frac{1}{2}$ inch thick; and the total weight of the castings is 162 pounds. The pit requires 1,000 brick. The total cost of the catch basin when laid in 1 to 3 cement mortar is \$17.00 to \$19.00, including castings, excavation, and the vitrified elbow.

Fig. 120, page 364, shows the standard catch basin of Providence, R. I.* This form differs from that shown in Fig. 119 in the form of the inlet and of the trap for the outlet. The latter is made of iron cast in a single piece, and is somewhat complicated in form, but a careful study of the two views shown in Fig. 120 will make the construction reasonably clear. The seal in Fig. 120 is better than that in Fig. 119; but the latter is used only with storm-water sewers and for such use this trap is sufficient. Not infrequently, however, the outlet of the catch basin is left untrapped; and sometimes an inlet is connected to a sewer without the intervention

* By courtesy of Otis F. Clapp, City Engineer

of either a catch basin or a trap. This practice is likely to clog the sewer.

Fig. 121, page 365, is the standard for Milwaukee, Wis.* This diagram is presented to show (1) the form of the inlet, (2) the method

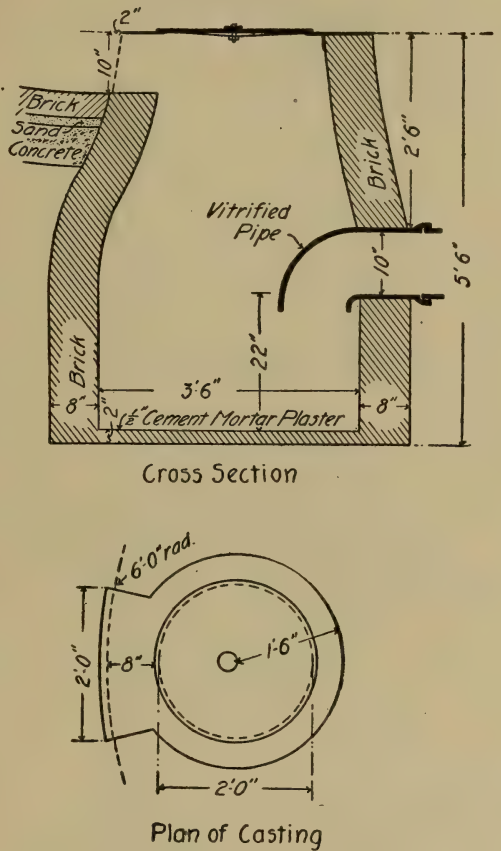

Fig. 119.—Champaign Catch Basin.

of preventing floating debris from entering the outlet, and (3) the method of ventilating the sewer.

Fig. 122, page 365, shows the standard form in St. Pancras Vestry, London, England.†

In England many earthenware catch basins or "gully pits"

* By courtesy of C. J. Poetsch, City Engineer.
† From a special report by William Nisbet Blair, Vestry Engineer.

are used. Some of these forms are quite complicated. American engineers object to earthenware pits on account of (1) their limited

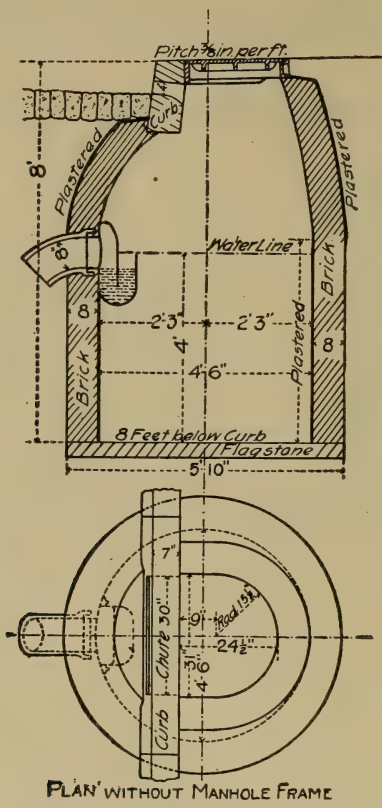

FIG. 120.—PROVIDENCE CATCH BASIN.

size, (2) their great cost, and (3) their liability to be broken by the weight and jar of the street traffic.

705. Location. The catch basin is usually placed near the curb with the cover in the sidewalk or the parking. It is objectionable to have the cover in the sidewalk, since (1) the cover itself is something of an obstruction to travel and is dangerous when it wears smooth or is covered with snow, (2) the clearing of the pit seriously interferes with the convenient use of the footway, and (3) in emptying the pit the sludge is likely to be spilled on the footway, and at best the odor is offensive. In some cities these objections are eliminated by placing the inlet at the curb line and conducting the drainage to a catch basin near the center of the street, one basin serving

for two or more inlets. Notice that the catch basin shown in Fig. 122 cleans out in the gutter.

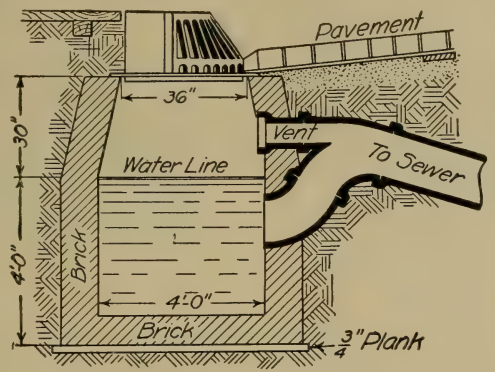

Fig. 121.—Milwaukee Catch Basin.

It is customary to place a catch basin at the corner of the curb. For additional objections to this location, see § 712.

The number and capacity of catch basins will depend upon the

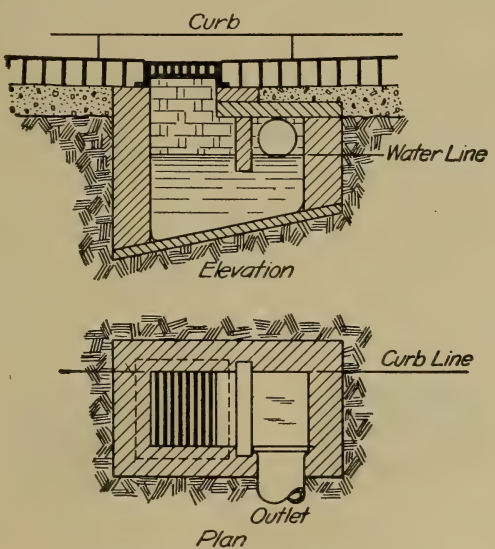

Fig. 122.—London Catch Basin.

area drained, the amount of rain, the grade of the gutter, etc. On streets having light or level longitudinal grades, catch basins may be constructed at intervals along the gutter as the circumstances require.

706. Form of Cover. When a catch basin or sewer manhole is located in a pavement, the shape and the surface of the cover require attention. The upper surface of the cover and also of its frame should be covered with projections to afford a good foothold and to prevent it from wearing slippery. The best form for the frame depends upon the material of the pavement. For macadam and asphalt the round frame is best, since it offers least obstruction to travel; the next best form is a square frame set diagonally to the line of travel. For a pavement made of bricks or stone blocks, the frame set with its sides parallel to the length of the street is best, because the bricks or blocks can be most closely fitted against this form. In Europe and in many American cities, it is customary to use only a square form, and to set it diagonally in macadam and asphalt pavements, and square in stone block and brick.

Often water-gate or stop-box covers are round in plan and have a convex surface, although the convex surface is very objectionable. The better form is a cover round in plan with a flat recessed top set flush with the pavement. Preferably the portion below the ground should be provided with a cast screw for adjusting the height. This form may be had of dealers in street-drainage goods.

707. The Inlet. In a general way, there are stone and cast-iron inlets. The former consist either of an opening between a stone cover and a stone floor, or a slot through the stone curb (see Fig. 120, page 364). This form is usually entirely open, but it is sometimes barred with one or two horizontal iron rods.

There is a great variety of cast iron inlets on the market, which may be classified as being straight or curved, and also as having a vertical or a horizontal opening. Fig. 123 shows an unprotected straight vertical inlet. Sometimes the opening is protected by

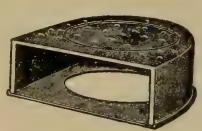

FIG. 123.

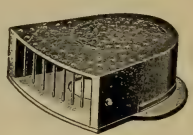

FIG. 124.

one or more horizontal or vertical rods. The latter are the better, as they offer greater protection against the entrance of debris—particularly sticks and boards. Fig. 124 shows a vertical front curved for a corner, having vertical bars. Fig. 125 and 126 are two styles of a form having both a vertical and a horizontal

opening. Notice that Fig. 122, page 365, has only a horizontal opening. A horizontal opening is not so good as a vertical one, since the former is easily stopped by a few leaves, and the accumulation of

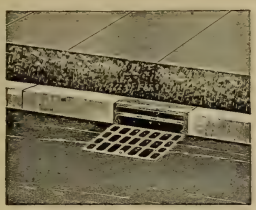

FIG. 125.

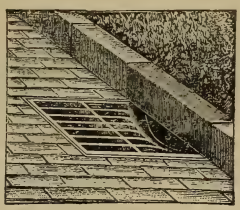

FIG. 126.

water makes the stoppage more complete; while the barred vertical opening is less easily obstructed, and as the water rises it can pour over the obstruction already formed.

708. Inlet without Catch Basin. It is sometimes desirable to connect two or more inlets to one catch basin—for example, see § 713. There are various forms of such inlets on the market and many cities have their own special designs. Fig. 127, page 368, shows the form of inlet used in such a case at Omaha, Nebraska. The entrance *A* is reduced by cast ribs to three openings 6×9 inches at the top and $4\frac{3}{4} \times 2$ inches openings at the bottom. The section *B* is rectangular in plan at both top and bottom. The section *C* is rectangular at the top and circular at the bottom, and fits into the hub of a vitrified elbow. Fig. 128, page 368, shows another form of curb inlet without catch basin. Fig. 129, page 369, shows a commercial form of inlet, which has an adjustable curb. It is made to fit various sizes of outlet pipe.

709. GUTTERS. The Material. Ordinarily the surface of the pavement adjacent to the curb serves as a channel to convey the drainage to the nearest inlet, i. e., the gutter is formed of the same material as the pavement. With an asphalt or macadam pavement, it is customary to lay brick or stone blocks in the gutters—with asphalt to prevent its deterioration from being continually covered with mud and water, and with water-bound macadam to prevent flowing water from disintegrating it.

A combined concrete curb and gutter (§ 737) is frequently used, particularly with asphalt, brick, or macadam on residence streets. A concrete gutter is objectionable on a macadamized street, on account of the crushed stone's wearing below the edge of the gutter,

a condition which interferes with the drainage; but if the macadam surface is reasonably well cared for, this objection is not serious. A

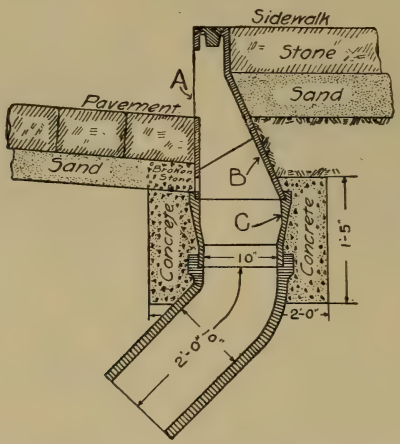

FIG. 127.—OMAHA INLET WITHOUT CATCH BASIN.

concrete gutter has been objected to for any pavement owing to the liability of a rut to form along its outer edge. In practice neither of these objections has proved to be serious. A concrete gutter is more efficient and looks better than one of any other available material except asphalt (see last paragraph of § 710).

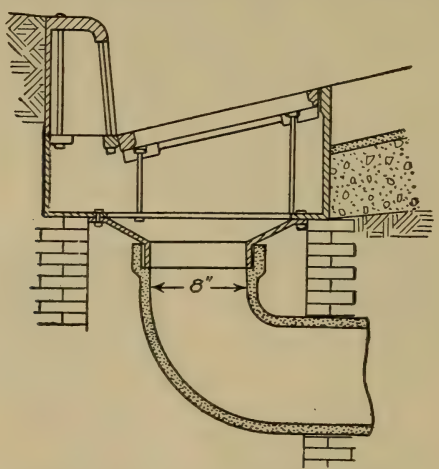

FIG. 128.—CURB INLET, CHAMPAIGN, ILL.

Usually the gutter is formed by continuing the ordinary slope of the pavement until it intersects the curb; but occasionally the

outer edge of the pavement is given an upward inclination, thus forming a flat V-shaped channel a little way from the curb. This construction makes an excellent channel for the water, but prevents the driving of a carriage close enough to the curb to allow people to step in or out easily.

In some cases the curb is set and the gutter formed before the pavement is laid, in which case the curb and gutter are constructed

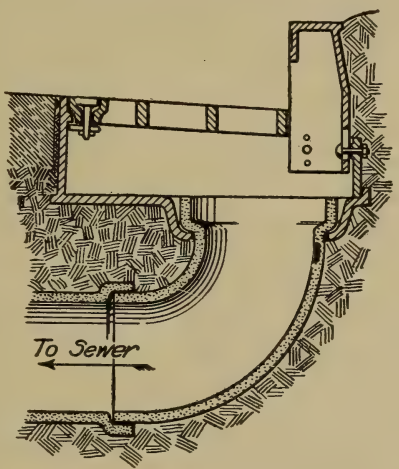

FIG. 129.—COMMERCIAL INLET WITHOUT CATCH BASIN.

as they would have been if the street were to be paved,—the gutter being composed of stone blocks, bricks, or concrete (§ 709). Sometimes a street is macadamized or graveled when it is not desired to incur the expense of setting a curb, in which case the gutter is built of cobble stones, or stone blocks, or bricks, in the form of a very flat V with the side next the property much the steeper.

710. Depth. Where a curb is used, the gutter should not be so deep as to present a high step for pedestrians, nor so shallow as to be in danger of being overflowed. Not infrequently gutters are made needlessly deep. It is easier to keep a curb in line with a shallow gutter than a deep one. On streets having a considerable longitudinal grade the gutter can have a uniform depth, inlets being inserted to draw off the surplus water; but on streets having nearly level grades, the gutter must increase in depth as the inlet is approached. This can be done easily with a stone curb, but not so easily with a combination concrete curb and gutter (§ 737), since the latter is usually made in moulds having a uniform cross section; and there-

fore with a concrete curb and gutter, it may be necessary to put a summit in the pavement to secure proper drainage of the gutters. Except in extreme cases, the gutter should not be deeper than 9 inches nor shallower than 3 inches; and ordinarily it should not be more than 8 nor less than 4 inches—usually it is 5 or 6 inches.

It may be necessary to modify the preceding rules when one side of the street is higher than the other (see § 693). In localities where there is a good deal of snow, the gutter must be deeper than stated above, for shallow gutters readily become clogged with snow and slush. In some northern cities, the snow is habitually allowed to pack upon the surface of the street to a depth of 6 or more inches, in which places the depth of the curb must be extremely deep to prevent the melting snow and water from filling the gutter and flowing over the sidewalk into the basements.

711. Grade. For most materials with which gutters are paved, it is improbable that the grade will be so steep as to do serious harm. Crushed stone and gravel are exceptions to this rule, however, and these materials must not be laid on too steep a grade. They may be used on a 2 per cent grade provided the volume of water is not too great.

The minimum grade permissible in the gutter will depend chiefly upon the material with which it is paved, but somewhat upon the cost of catch basins. Almost any grade can be obtained by establishing catch basins close together and raising the gutter half way between them. In a number of cities the minimum grade of gutters paved with granite blocks, bricks, rectangular wood blocks, or macadam is 1 in 300 or 400. Except under very favorable circumstances, a slope of 1 in 200 ($\frac{1}{2}$ of 1 per cent) should be regarded as the minimum.

Asphalt decays if continually wet, and therefore the condition governing the minimum permissible grade is different for that than or other materials. With a slope of less than 1 per cent, the gutter will not keep itself clean, consequently the asphalt will decay owing to the action of mud and water; and hence asphalt should not be laid in a gutter having a fall of less than 1 in 100. If this fall can not be obtained, a concrete gutter should be used, or the gutter should be paved with vitrified brick or carefully dressed granite blocks.

712. Drainage at Street Intersection. In most cities it is customary to construct catch basins at the corner of the curb, using an inlet with a curved face. This practice is very objectionable.

If the walk across the street is elevated above the pavement, it

is necessary either to carry the water under the walk in a pipe, or to stop the cross walk within a short distance of the curb to leave a channel for the water. The latter method is necessary where there is much water. Frequently this channel is left open at the top, and sometimes it is covered with a cast iron plate with one edge resting in a rabbet in the curb and the opposite one in a head stone or false curb set at the end of the cross walk. The covered gutter is much better than the open one, although the cast plates are frequently struck by wheels and broken, and often get displaced. This solution of the problem is further objectionable since a wheel in turning the corner must surmount the first raised cross walk, then descend to the bottom of the gutter, and finally climb over the second cross walk. The face of the inlet usually has a depth of 8 to 12 inches below the top of the curb; and hence if the sidewalks are wide or the parking is narrow, the shock to a vehicle going around such a corner is considerable.

If the cross walk is not elevated, the step from the curb to the bottom of the gutter is uncomfortably high, and besides pedestrians are compelled to cross the gutter where there is the most water.

713. A much better arrangement than either of the above is to place an inlet at each side of the corner. Each inlet may have its own catch basin, or the two may connect with a single pit by means of tile or vitrified pipe underground. Fig. 130, page 374, shows such an arrangement. Instead of this plan, the two inlets at each of the four corners of the street intersection may be connected with a single catch basin placed in the middle of the intersection or in other suitable location. The inlet not connected directly with a catch basin can be made by inserting the hub of a curved vitrified pipe in the bottom of a cast inlet-box (see Fig. 127, 128, and 129).

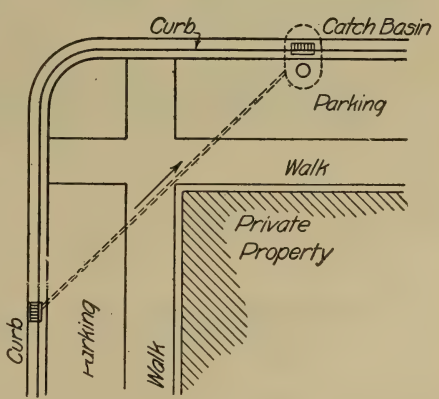

Fig. 130.—Inlets at Street Corner.

The advantage of the method shown in Fig. 130 is that it allows the intersection to be paved almost level with the top of the curb, and hence there is no obstruction to either pedestrian or vehicular travel. The only objection to it is the expense for either the extra

catch basin or the extra inlet and connecting pipe, but the advantage is well worth this comparatively small cost.

714. Where there are no storm-water sewers, the gutter is sometimes carried across the street intersection. This is objectionable at any season, and particularly so when the gutter is filled with snow or ice. If the gutter is deep or the grade is steep, the water may be carried under the intersection by a shallow culvert with cast iron top, or better in a cast iron pipe; but if the gutter is shallow or the grade nearly level, the road surface should be raised a little to give room for a cast iron storm-water drain under the roadway. The elevated intersection may be a slight obstruction to travel, but it is preferable to two open gutters.

715. Elevated Foot-way Crossing. To aid pedestrians in crossing the water in the gutter, it was formerly the practice to raise the pavement in the line of the crossing so that the surface of the foot-way

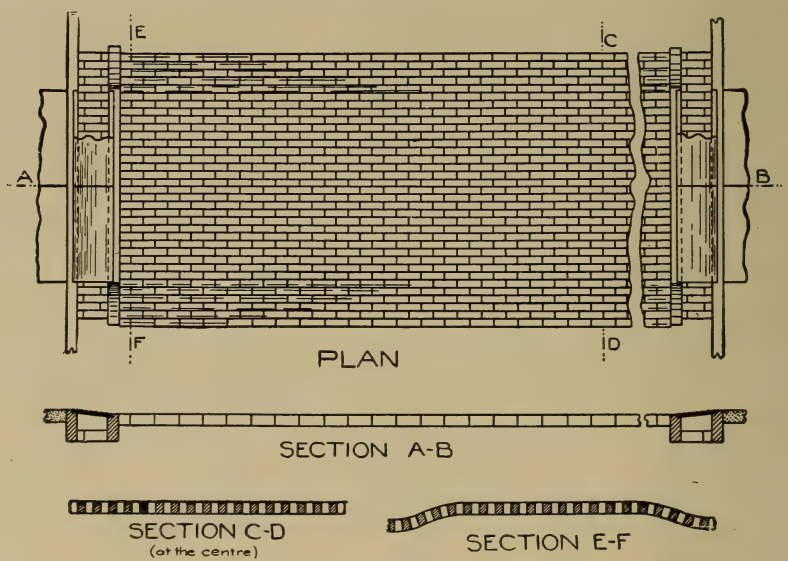

FIG. 131.—ELEVATED BRICK CROSSING.

was level from the crown of the carriage-way pavement to the top of the curb, and leave a channel next to the curb which was either left open or bridged with a cast iron plate. Fig. 131 shows the details of an elevated brick crossing. Notice that Fig. 131 has a limestone curb and a brick gutter. Fig. 132 and 133 show the gutter at the end of an elevated brick crossing when a con-

crete curb and gutter is employed. The chief difference between Fig. 132 and 133 is in the form of the false curb or head stone on the side of the gutter toward the center of the street. The difference in the merits of the two methods is mainly in the cost, Fig. 133 usually being slightly the cheaper. In both cases there is a drop of 1 inch in the width of the cast iron bridge plate. Of course, the crossing could be carried level from gutter to gutter, or more drop could be put into the gutter plate.

It has always been recognized that as far as the use of the carriage-way pavement is concerned, an elevated crossing is undesir-

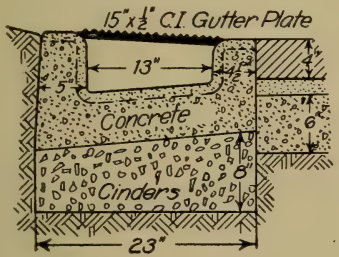

FIG. 132.—GUTTER FOR ELEVATED BRICK CROSSING WITH CONCRETE FALSE CURB.

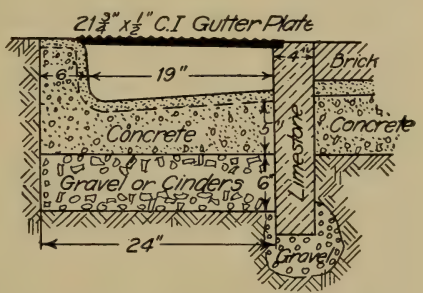

FIG. 133.—GUTTER FOR ELEVATED BRICK CROSSING WITH LIMESTONE FALSE CURB.

able, particularly where the pavement is used by a large number of vehicles or where there is considerable rapid travel; but since the introduction of the automobile, the elevated crossing is very undesirable. The elevated crossing is a serious obstruction also to vehicles rounding the corner; and besides the cast iron crossing plates are easily displaced and are frequently broken. The elevated crossing should not be used.

716. SURFACE DRAINAGE. The drainage of the surface of the pavement is provided for by making the center of the pavement higher than the sides. The principle governing the amount of crown for pavements is somewhat different from that of earth, gravel, or water-bound macadam roads. First, a hard, smooth and practically impervious pavement needs no crown for the drainage of the surface; and on such a pavement, the only advantage of a transverse slope is to drain shallow depressions due to faulty construction, wear, or a settlement of the foundation, and to aid the rain in washing the pavements. Second, the surface of the pavement has no tendency to wash; and hence the crown need not be increased on a grade as in

the case of earth roads. The less the crown the better for travel, and the more uniformly will the travel be distributed over the pavement, although a slight crown is inappreciable in either of these respects. Therefore pavements require only crown enough to drain depressions of the surface due to faulty construction, to wear, or to settlement of the foundation; and the crown may decrease as the grade increases.

717. Crown. There has been much discussion as to the best form of the surface of a pavement. Some claim that it should be a continuous curve, while others contend that it should consist of two planes meeting in the center. The curved profile is defective in that it gives too little inclination near the middle, the result being that the pavement wears hollow in the center and permits water to stand there. To overcome this objection some engineers raise the center of the pavement $\frac{1}{2}$ or $\frac{3}{4}$ of an inch above the curved cross section. The objection to the two planes is that the sides wear hollow and hold water. An advantage of the curved profile is that the center of the street, which is the part especially devoted to travel, is nearly flat; while the sides, which have the greater inclination, are occupied by teams standing at the curb. Another advantage of the curved profile is that it gives a deeper gutter, which confines the storm water to a smaller portion of the street and reduces the interference with pedestrian travel.

It is sometimes claimed that the curved form will support the greater load, because of its arch action; but the arch action of a pavement is entirely inappreciable, owing to the flatness of the arch, to the imperfect fit of the so-called arch stones, and to the instability of the abutments or curbs.

The surface is usually a continuous curve—generally a parabola.

718. *To Lay out a Parabolic Crown.* In Fig. 134 the curved line $C\ B$ represents the surface of the finished pavement. C is the center of the pavement; and $C\ D = A\ B =$ the amount of the crown.

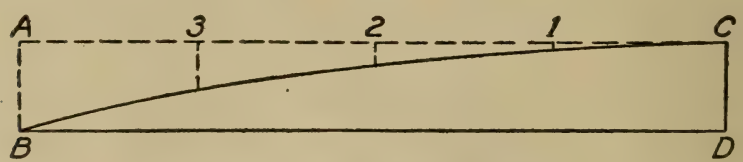

FIG. 134.—PARABOLIC CROWNED PAVEMENT.

To find the distance from the line $A\ C$ down to the curved line $C\ B$, divide the half width of roadway, $A\ C$, into any number of equal

parts, say n, and designate the distance from the point 1 on $A\ C$ vertically down to $B\ C$ by x; then by the principles of the parabola, $x = \frac{A\ B}{n^2}$, and the distance from point 2 down to the road surface is $2^2\ x$ or $4\ x$, and the distance from 3 is $3^2\ x$ or $9\ x$. In practice a string with knots in it to represent the points of division of $A\ C$ is stretched from the top of the curbs, and then the ordinates computed as above are measured with a pocket rule.

719. When construction begins, it is wise to give the one in charge of the work a drawing somewhat like Fig. 135, showing

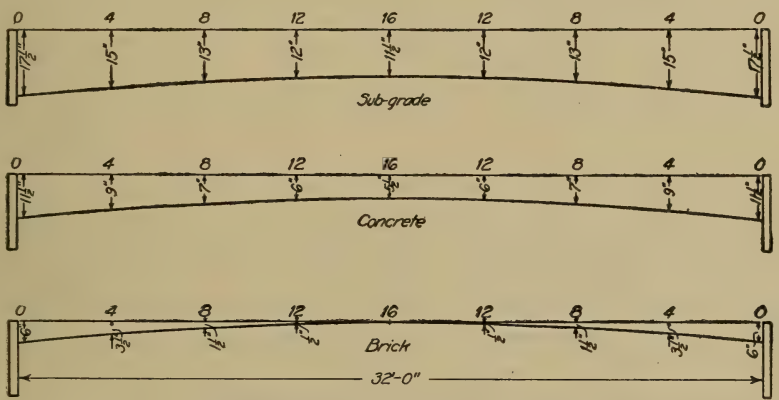

Fig. 135.—Method of Showing Crown of Pavement.

the relation between the top of the curbs and the cross section of the subgrade, the top of the concrete, and the top of the finished pavement. Such a drawing prevents misunderstandings and disputes. Notice that the curves in Fig. 135 are not exact parabolas, the ordinates at 4 and 12 being $\frac{1}{8}$ inch too long; but this is sufficiently exact, since it is not possible to secure mathematical precision in this class of work.

720. Rules for Amount of Crown. The practice of different cities is not at all uniform as to the amount of crown. Numerous empirical formulas have been proposed for the crown of pavements; but there is not much harmony between them.*

721. *Washington Formula.* Since 1894 the Engineering Department of the District of Columbia has employed the following formula: $C = w(100 - 4p) \div (6300 + 50p^2)$, in which C = the

* For a list of many such formulas, see *Engineering News*, Vol. 63 (1910), p. 516–18.

crown in feet, w = the distance between the curbs in feet, and p is the longitudinal grade of the pavement in percentage. Notice that the crown decreases as the longitudinal grade increases.

722. *Rosewater Formulas.* Apparently the formula proposed in 1902 by Andrew Rosewater, then City Engineer of Omaha, is most frequently used. The latest Rosewater formula is as follows: "The crown for asphalt is: $C = w\,(100 - 4p) \div 5{,}000$, in which the nomenclature is as in the section next above. For brick, stone block, or wood block, the crown is five sixths of that for saphalt." A formula for crown formerly used in Omaha gave a less crown than the above rule for brick, stone block, and wood block, and a much less crown for asphalt. The former formula is:

for brick, stone block, and wood block, $C = (20 - p) \div 1{,}600$
for sheet asphalt $C = (9 - p) \div 600.$

The latter formulas are still used by many cities.

Notice that in the preceding rules the crown is decreased as the steepness of the longitudinal grade increases, which is proper. Also notice that according to these rules, the crown of sheet asphalt is more than that of the other kinds of pavements mentioned, which is contrary to the practice of many cities. Considering only the smoothness of the surface, it appears that asphalt should have the least crown; but considering only the fact that asphalt rots when continually wet, it appears that asphalt should have a large crown.

723. The above rules for crown must be modified somewhat when the two sides of the street are not at the same elevation—see § 693, page 357.

724. *Recommendations of A.S.C.E. Committee.* For the crown recommended for various road and pavement surfaces by a committee of the American Society of Civil Engineers in 1917, see Table 16, page 65.

725. Dished Pavements. The early pavements in this country and at present those in some cities in Europe and South America, slope from both sides towards the center. In this form the most valuable part of the street is devoted to drainage purposes, and it is difficult to carry the water to an intersecting street.* The pavements of alleys usually slope to the center. This form is better for

* The single-gutter street pavement was ably advocated by W. G. Kirchoff in a paper before the Wisconsin League of Municipalities—See *Engineering and Contracting*, Vol. 44 (1915), p. 190–91.

alleys than a gutter at each side, since it keeps the storm water from flowing along the side of buildings and possibly interfering with light areas, cellar stairways, etc., and it also carries the water over the sidewalk with less annoyance to pedestrian travel.

CHAPTER XIV

CURBS AND GUTTERS

728. Curb. A curb is a plank or slab of stone set at the edge of the roadway to protect the sidewalk or tree space and to form the side of the gutter. Curbs are not usually set except where the street is paved, but they greatly improve the appearance of an unpaved street and protect the grass plats at the side of the street, particularly during the muddy season.

Curbs were formerly made of natural stone, but concrete curbs, usually combined concrete curb and gutter, are increasing very rapidly in recent years—chiefly because of the decrease in the price of portland cement. Natural stone is used now only in the vicinity of quarries of suitable stone. Granite is the best natural stone, but it is usually very expensive. Limestone and sandstone are frequently used, but they are generally too easily chipped or broken. Concrete unless made with unusual care or protected by steel on the edge, is too friable for a business street where heavy loads frequently back up against the curb.

729. Stone Curb. Granite curbs are obtained in large quantities in several states, notably Maine, New Hampshire, Massachusetts, Connecticut, New Jersey, Pennsylvania, Georgia, Wisconsin, Missouri, South Dakota, California. Husdon River bluestone, a variety of sandstone commercially known as bluestone, is much used for curbs, on account of its hardness, durability, and great transverse strength. It is evenly bedded, splits with a smooth surface, and is found in large quantities in the counties of the state of New York adjoining the Hudson River from Albany to New York City. The sandstones most used for curbs are the following: A gray stone from Berea, Ohio; a brownish red stone, known as Medina sandstone, obtained in the State of New York on the shore of Lake Ontario; a gray, yellow, brown or red stone from Potsdam, N. Y.; a metamorphic sandstone from Sioux Falls, South Dakota, known as Sioux

Falls quartzite; and a light-pink stone from Sandstone, Minn., known as Kettle River sandstone.

730. The thickness should be sufficient to give strength to resist the blows of wheels and to prevent the frost in the earth back of the curb from breaking it off at the top of the gutter. The curb is usually 4 to 6 inches, depending upon the quality of the stone and the locality. The depth must be sufficient to prevent the thrust of the earth behind the curb from overturning it, and is usually 18 to 24 inches. If the sections are too short, it is difficult to keep them in place and the general appearance is not good; and if they are too long, it is difficult to handle and set them, and nearly impossible to get a firm bearing on the bottom. They usually vary from 3 to 8 feet in length.

The exposed face of the curb should be bush-hammered or axed; and where the sidewalk extends to the curb, the back also should be smoothly dressed so the sidewalk may fit closely against the curb. The upper face should be cut to a slight bevel with the front face, say $\frac{1}{4}$-inch to the foot, so that when the face of the curb is set with a little inclination backward, the top face will be level or slope downward and to the front a trifle. The pavement slopes toward the gutter, and therefore a wagon wheel inclines toward the curb; hence the curb is set leaning back a little to prevent a wheel from striking the face when running at the inner edge of the gutter and also to secure increased stability. The curb is usually cut with a square corner at the outer upper edge; but it would be better if this corner were rounded off slightly, say to a radius equal to one third of the thickness of the curb, to decrease the tendency to chip. The ends of the sections should be smoothly dressed to the exposed depth, and the part not exposed should be knocked off so as to permit the dressed ends to come into close contact. The ends should fit closely for appearance and to prevent the earth, particularly if sand, from running from behind the curb between the sections into the gutter, or to prevent the sand cushion of a brick pavement from running from under the bricks into these cracks and possibly through them into holes behind the curb. In a number of European cities, notably Brussels, the curb is cut with a tongue in one piece which fits into a groove in the next piece, to aid in keeping the curb to line.

The curb should be set with a uniform batter, in a straight line, and on a regular grade. To fulfill these conditions requires careful work in the first place, and to prevent the curb from subsequently getting displaced requires proper design and thorough workman-

ship. The trench in which the curb is to be set should be dug 4 to 6 inches below the base of the curb to allow for a layer of gravel on which to set the stone; and the width of the trench should be at least three times the thickness of the curb to allow room for ramming the earth around the stone. The bottom of the trench should be made smooth and be thoroughly consolidated by ramming, and the gravel also should be compacted. Where gravel is expensive, it is dispensed with, the curb being set upon brick or stone. In filling the trench, the earth should be thoroughly rammed in layers not more than 4 inches thick. Where gravel is plentiful, it is sometimes specified that the trench shall be filled with gravel to 8 or 10 inches from the top.

In the past there has been so much trouble in keeping curbs in line, that within recent years there has been a general tendency to set the curb in a bed of concrete—particularly when concrete is used for the foundation of the pavement. A 6-inch layer of concrete is deposited in the trench and the curb set upon it, after which the trench is filled with concrete on the street side up to the base of the proposed pavement and on the back side nearly up to the top of the curb. When set in concrete, the curb does not need to be as deep as otherwise, since the concrete then practically becomes a part of the curb.

731. Owing to the difficulty of keeping stone curbs in line or rather owing to the expense of setting them so they will certainly stay in line, stone curbs are becoming much less common than formerly. They are being replaced by concrete curbs or more frequently by combined concrete curb and gutter (§ 737).

732. *Cost.* In most localities, split sandstone or limestone curbing 4 to 6 inches thick can be had for 30 to 40 cents per square foot f.o.b. cars at the destination; and often sawed stone can be had at about the same price. The additional cost of a bush-hammered or axed surface will vary with the hardness of the stone and the degree of the finish, and curved sections will cost 30 to 50 per cent more than straight pieces. Hudson River bluestone (sandstone) curbing 5 inches thick costs about 30 cents per square foot. Granite curb costs from 40 to 50 cents per square foot, depending upon locality and thickness.

For more definite information, see the price reports in current technical journals.

733. Concrete Curb. In some sections where suitable stone for curbing is not readily available, curbs have been made of portland

cement concrete. Owing to the decreasing price of cement, this form of curb is coming into more common use. It is usually made about 6 inches thick and 18 or 20 inches deep. If well made, it does excellently for residence streets.

For suggestions concerning the construction of concrete curb, see § 738–47.

734. The exposed corner of a concrete curb, particularly on a business street, is sometimes protected by a steel angle or special form which is anchored to the body of the concrete by lugs or a special stem. Several of these forms are very efficient, but as they are patented nothing more will be said here. For particulars consult the advertising pages of technical journals.

735. *Cost.* Table 37, page 382, shows the cost, as determined by 38 time studies, of the concrete curb shown in Fig. 136. It was laid in sections 6 feet long with thin metal partitions between. At first a 1 : 2 : 5 mixture was used for the body, but later a 1 : $2\frac{1}{2}$: 6; and the facing was 1 : $1\frac{1}{2}$: $1\frac{1}{2}$. The proportions were accurately measured by volumes. The concrete was mixed by hand on a wood platform in the middle of the street. As soon as the concrete had set sufficiently, the front forms were removed and the face of the concrete was scrubbed with steel brushes when the concrete had set hard enough to require them, but usually with stiff-bristle brushes.

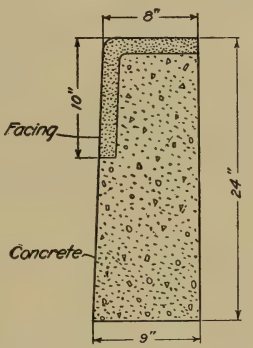

Fig. 136.—Cross Section of Curb.

736. Gutters. Incidentally the construction of the gutter has already been considered in § 709–11, which see.

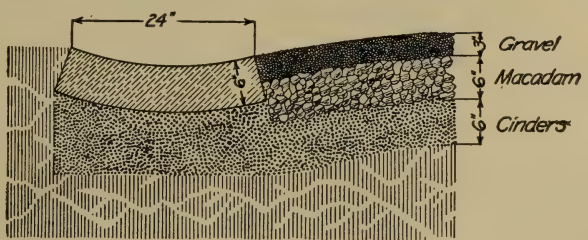

Fig. 137.—St. Louis Concrete Gutter or Park Drive.

Fig. 137 shows a concrete gutter used in St. Louis, Mo., for park drives.

737. Combined Concrete Curb and Gutter. In recent years the construction of combined concrete curb and gutter built in place has become very general in the smaller cities, and in resi-

TABLE 37

Cost of Concrete Curb *

Superintendence and Over-head Expenses not Included

Ref. No.	Item	Cost Cts. per Lin. Ft.			Aver. per Amt. of Total.	Feet Completed per Man-hour.		
		Min.	Max.	Aver.		Min.	Max.	Aver.
	Labor:							
1	Foreman @ 37½c. per hr.	1.1	3.9	2.2	4.7			
2	Water boy @ 10c. " "	0.4	1.3	0.6	1.3			
3	Trenching @ 18c. " "	2.2	9.4	4.9	10.5	1.9	9.6	4.1
4	Placing forms @ 35c. " "	1.0	10.4	4.2	9.0	2.5	26.4	7.2
5	Removing forms @ 25c. " "	0.5	5.2	1.8	3.8	2.0	38.0	7.6
6	Concrete @ 18c. " "	2.6	9.5	4.3	9.2	1.2	6.8	3.2
7	Facing @ 18c. " "	0.9	2.9	1.7	3.6	6.5	20.4	10.6
8	Finishing @ 35c. " "	1.8	10.7	4.8	10.3	3.7	20.4	8.3
9	Scrubbing @ 35c. " "	0.4	3.4	1.7	3.6	5.0	48.1	11.4
10	Back-filling @ 18c. " "	0.3	2.0	1.3	2.8	5.9	51.0	14.1
11	Total for labor	11.2	58.7	27.5	58.8			
	Materials:							
12	Cement @ $1.20 per bbl.	6.2	8.9	7.6	16.2			
13	Sand @ 0.75 per cu. yd.	1.2	1.5	1.4	3.0			
14	Gravel @ 1.90 " " "	6.0	7.7	6.9	14.7			
15	Facing @ 1.75 " " "	0.4	0.7	0.6	1.3			
16	Lumber, 1½-inch spruce	1.0	1.0	1.0	2.1			
17	Water, waste, etc.	1.5	2.0	1.8	3.9			
18	Total for materials	16.3	21.8	19.3	41.2			
19	Grand Total	27.5	80.5	46.8	100.0			

* *Engineering and Contracting*, Vol. 43 (1915), p. 61.

dence districts of larger cities. Such construction is cheap, durable, efficient, and good in appearance. It is very popular with brick and asphalt where the grades are very flat, and is often used with a crushed-stone pavement. Fig. 138 shows the cross section of the usual form. Notice that the face of the curb is battered. This is important, since the pavement is crowned, and therefore the plane of a steel wagon-tire is inclined. Consequently if the face of the curb is vertical, the tire will strike it at its upper edge; but if the face of the curb makes an angle with the pavement greater than 90°, the tire will strike the bottom of the curb and do much less damage.

To prevent damage by the striking of steel tires, the curbs to private drives, particularly narrow ones, usually have a convex face.

Fig. 139 shows the form of combined concrete curb and gutter employed in St. Louis, Mo.

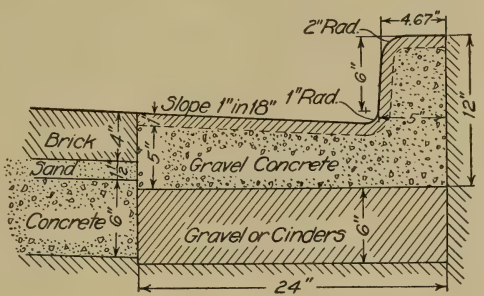

Fig. 138.—Standard Concrete Curb and Gutter.

738. Foundation. A trench is excavated 4 to 6 inches wider than the base of the concrete, and a layer of cinders or gravel 4 to 8 inches thick (usually 6 inches) is laid, flooded with water, and then thoroughly tamped. Upon this foundation is erected the forms in which the concrete is to be laid.

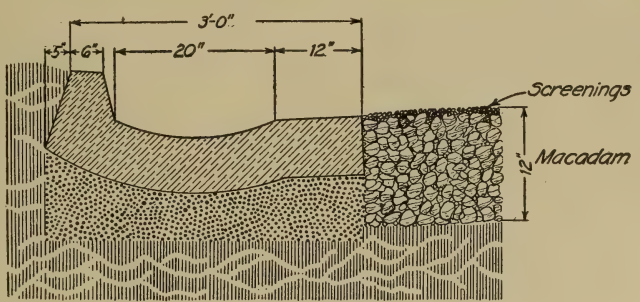

Fig. 139.—St. Louis Concrete Curb and Gutter for Park Drive.

739. The Forms. There are two general methods of constructing these forms: 1. Some contractors lay alternate sections in boxes about 6 feet long, and subsequently place boards against the sections first laid and construct the remaining sections. This plan is more expensive and does not secure as good alignment as the method described below. 2. A continuous line of plank is set for the back of the curb and another for the front of the gutter. These planks are

kept in place by stakes on both sides. Partitions are inserted so as to divide the mass into sections 6 or 8 feet long.

Two forms of partitions are in common use. Sometimes these partitions are plank $1\frac{1}{2}$ or 2 inches thick, in which case the sections are laid alternately, the partitions being removed before the second series of blocks are formed. In other cases, the partitions are made of steel $\frac{1}{8}$ or $\frac{3}{16}$ inch thick, and are left in position until the blocks are practically finished. There is but little choice in construction between the two forms of partitions, except that it is difficult to withdraw the steel partitions without chipping the surface—see § 745.

740. The form for the front of the curb is made by setting a plank $1\frac{1}{2}$ or 2 inches thick against the front of the upper part of the partitions and clamping it to the plank at the back of the curb with steel screw-clamps. The lower edge of this plank is rounded to make the curve between the face of the curb and the top of the gutter.

The concrete for the base of the gutter is deposited and tamped, and then the mortar for the face of the gutter is applied—all before the form for the front of the curb is clamped into place.

741. Mixing and Laying. For information concerning materials proportioning, and mixing, see Art. 1, Chapter VII,—Concrete Roads.*

The proportions of the concrete will depend upon the gradation of the aggregates (§ 418–24), and upon whether the surface is to consist of a richer mixture than the body of the concrete or whether the surface is to be finished integral with the body. Usually a 1 : 2 : 4 or a 1 : 3 : 4 mixture is used for the body, and a 1 : $1\frac{1}{2}$ or 1 : 2 mixture for the facing mortar.

742. The upper face of the gutter slab is finished by adding a 1-inch coat of rich mortar and tamping and troweling it, exactly as in concrete sidewalk construction. It is important that the surface of the concrete be free from mud or dust when the topping is deposited; and this is a condition quite difficult to secure, because the curb and gutter is built in a narrow trench, often a considerable distance below the surface, and usually with the excavated material piled near. It is also important that the facing be deposited before the concrete has begun to set.

* For a full discussion of the method of testing the cement and proportioning the concrete and of the relative merits of gravel and broken-stone concrete, together with tables of quantities, strength, cost, etc., see A Treatise on Masonry Construction by Ira O. Baker, 10th edition, pp. 745, 6×9 inches, John Wiley & Sons, New York City.

743. There are three distinct ways of finishing the exposed face of the curb:

1. The surface is faced with a rich mortar built integral with the body. This may be obtained in either of three ways, of which the first is most likely to secure a firm union between the backing and the facing. *a.* A layer of rich mortar is deposited against the lower third or half of the front form, and then the concrete backing is deposited and both are well tamped; and the process is repeated once or twice until the form is full, when the top surface of the curb is finished by adding a 1-inch layer of facing mortar. *b.* A 1-inch plank is inserted inside of the front form, and the concrete for the body is deposited and tamped; then the 1-inch plank is carefully removed, and a rich facing mortar is tamped into the vacant space. *c.* Instead of the 1-inch plank as above, use a steel plate $\frac{1}{8}$ or $\frac{3}{16}$ of an inch thick having vertical 1-inch angles riveted at intervals along its length. This plate is inserted behind the front form, the concrete is deposited, and then the facing mortar is deposited between the front form and the steel plate; next the steel plate is removed, and the facing mortar and the concrete are thoroughly tamped.

2. The second method of finishing the face of the curb is to mix the concrete rather wet, and spade the face, i. e., after the concrete is deposited force a flat spade or its equivalent vertically against the back of the front form, and then push the handle away from the form to an angle of 20° or 30° and withdraw the spade. If properly done, this forces the larger stones away from the face and allows enough mortar to flow out against the form to give a solid face and permit a good finish of the surface. This makes the strongest face of any of the methods; but it is not popular with contractors, since to get a solid face it is necessary to mix the concrete so wet as to greatly delay the finishing of the face, which is objectionable for several reasons.

3. Sometimes a rich face is obtained by plastering the surface after the forms are removed. But this method necessitates using dry concrete in the backing, so as to remove the forms early, and consequently is likely to give a weak and porous surface upon which to apply the mortar. It is nearly impossible by this method to secure a firm union between the plastering and the backing; and the plastering is nearly certain to be knocked off by passing wheels (particularly during the excavation of the roadway when the passing wheels are heavy and the concrete is weak) and to be spalled off by

the pressure due to the temperature expansion of the curb. Although this method is sometimes used, it should never be permitted.

744. Finishing the Surface. There is a difference of opinion as to whether the surface should be considered finished when it has been troweled, or whether it should be afterwards brushed with a slightly wet brush. An ordinary flat paint brush, with extra heavy bristles, cut off about 1 inch below the wood portion, may be used for this purpose. The objections to the trowel-finished surface are that the trowel marks show more or less, and that the surface has a glaze or shine clearly indicating that the stone is artificial; while the brush finish has a uniform dull surface similar to a smoothly dressed natural stone. The objections to the brush-finished surface are that the brush leaves a porous surface that is not so durable as a trowel-finished one, which objection has considerable force if the surface is not first thoroughly troweled and if the brush is not used lightly. The less the troweling and the more the brushing, the more rapidly the surface can be finished; and hence it is difficult when brushing is permitted to prevent the slighting of the work. Both methods of finishing are employed by competent engineers; but the trowel finish is more common.

Recently a method of finishing by drawing a template over the curb and gutter has been introduced. The few trials made seem to show that this method is a little less expensive than finishing with a trowel, but that it gives a better general appearance and a better alignment, particularly at the joints.

745. Expansion Joints. Concrete curbs and also combined curbs and gutters should be built in sections 6 or 7 feet long with open joints to allow for expansion. If adequate space for expansion is not provided, the compression due to expansion is likely to crush and splinter the curb at the joints, and split off the mortar face or the plastering. Many such failures occur. For a discussion of a similar problem, see Contraction Joints in the Chapter on Concrete Roads (§ 465–68). Sometimes no provision is made for expansion, the curb or curb and gutter being made continuous with false joints marked at intervals. Sometimes the curb or curb and gutter is built in alternate sections without any expansion space between adjoining sections, the joints being simply a line of weakness which serves to prevent an unsightly crack if a section is displaced by frost or by the lateral pressure of the earth. The curb and gutter should be a practically permanent asset, and hence the prevention of its destruction by temperature changes is an important matter. One of

three means may be employed to prevent failures at the joints of curbs and gutters due to expansion.

1. The gutter flag and the curb are cut into short sections after being laid, much as a sidewalk slab is separated into short sections. The expectation is that the open joint will afford sufficient space for expansion; but it is likely to be filled on the face during the finishing of the face of the curb or gutter, which is particularly bad if a mortar face is used or if the exposed surface is plastered. Generally the open joint is reasonably successful for a time; but is likely to become filled with dirt and cease to be effective, and besides the open joint in the curb permits the earth behind the curb to escape, or with brick or block pavements the open joint in the gutter permits the sand cushion to escape.

2. Instead of cutting the curb and gutter as described in the preceding paragraph, it is much more common to insert steel diaphragms or partitions in the forms at intervals of 6 or 7 feet, which are withdrawn as the face of the curb and gutter is finished. These partitions are usually $\frac{1}{8}$ or $\frac{3}{16}$ inch thick. This joint is more efficient than the one described above, and is easier to construct; but it is open to substantially all of the objections to the preceding one.

3. Occasionally partitions consisting of one or two thicknesses of tar paper or one thickness of tar or asphalt felt are inserted in the forms at intervals of 6 or 7 feet; and after the face of the curb and gutter has been finished the paper or felt is cut off with a sharp knife a little below the surface of the concrete.

746. Whatever the method of constructing the expansion joint, it should be in a vertical plane perpendicular to the face of the curb, or one section may push past the other.

With any form of expansion joint, there is danger that the expansion of the straight curb will dislocate the curved curb at the corner of the block and at the alley return. This can be prevented by making an extra wide expansion joint near the corner. This joint may be $\frac{1}{2}$ to 1 inch wide according to the length of the block and the temperature when the curb is constructed; and it should be filled with tar pitch or asphalt. A number of proprietary compounds are upon the market for this purpose, made in sheets of different thicknesses.

747. Curbs are frequently damaged by being pushed over or broken by the expansion of cement walks. The remedy is to insert an expansion joint between the end of the walk and the back of the curb, or better in the joint in the walk one section back from the curb.

The expansion joint may be filled with tar paper or felt; or a thin board may be inserted during the construction, and after the concrete has set the board is withdrawn and the space is filled with tar pitch. The joints must occasionally be re-filled—preferably once each year.

748. Cost. The cost will depend upon the price of labor and materials, and upon the proportions of the mortar of the face and the concrete of the body. The amount of cement required will vary a little with the percentage of voids, but will depend chiefly upon the proportions of the mortar and the concrete.

The following data are for laying more than a mile of combined curb and gutter of the form shown in Fig. 138, page 383. The proportions of the facing mortar was 1 : 2; and that of the concrete 1 : 3 : 4 washed gravel. A barrel of portland cement made enough 1 : 2 mortar for the facing on 33 linear feet. The length of finished curb and gutter laid with a barrel of cement was 16 feet, with a variation of 1 per cent either way on different days. A yard of sand and pebbles laid 18 lineal feet. The loss of gravel in transportation and handling, and the shrinkage in tamping was nearly uniformly 20 per cent. The average length of curb and gutter completed, including straight work and curved returns at streets and alleys, and also including excavation, per man per hour was 0.333 foot. The trench was excavated before the roadway was excavated. The concrete was mixed in a batch mixer which discharged directly into the trench. The two finishers received 60 cents per hour, the three men setting face forms 35 cents, and the remainder 25 cents. The working force of 18 men when constructing forms and laying curb and gutter was divided as follows:

1 foreman and finisher,
1 finisher,
2 men setting face forms,
3 men setting back forms,
2 men wheeling and tamping cinders,
2 men running concrete mixer,
2 men feeding concrete mixer,
2 men mixing face mortar by hand,
1 man wheeling facing mortar,
1 man spreading facing mortar,
1 boy carrying water, etc.

The contract price in 1916 for the curb and gutter, including excavation and back filling, was 50 cents per lineal foot.

749. Double Curb and Gutter. Fig. 140 * shows the details of the form of the concrete double curb and gutter referred to in Fig. 114, page 357.

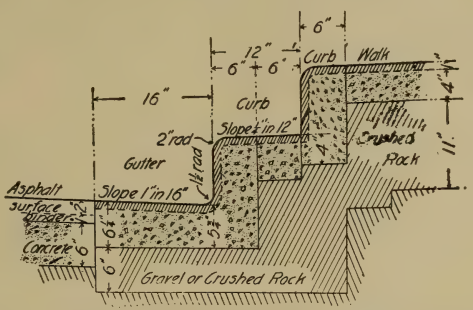

FIG. 140.—DOUBLE CURB AND GUTTER.

750. Curb and Gutter at Private Driveway. Fig. 141, page 390, shows the arrangement of the combined concrete curb and gutter at a driveway to a gate or a building. The radius of the curve at the corner of the curb is too small, as a radius of 4 or 5 feet would be better.

751. Merits of Concrete Curb and Gutter. The advantages of the combined concrete curb and gutter are: 1. It is usually cheaper, particularly if account be taken of the fact that the gutter occupies space that otherwise would be paved. 2. The alignment of the curb is better and more permanent. 3. The appearance is better. 4. Usually the concrete is more durable than a natural stone of equal cost. 5. The gutter is smooth, and easily cleaned.

A concrete curb is suitable only for residence streets, but is more durable for a business street than soft sandstone or limestone.

752. Other Forms of Curbs. About 1889 there was constructed on two streets at Washington, D. C., a concrete curb and gutter having at the inner lower edge of the curb a 4× 4-inch conduit for telegraph and telephone wires, with hand holes about 50 feet apart. The experiment was not considered successful, and the conduit was never used for wires.

From time to time advertisements appear of burned clay curbs; but none have been seen which are not so thin as to be easily broken, and so constructed by sections fitted together as to be unstable.

753. RADIUS OF CURB AT STREET CORNER. As far as vehicular traffic is concerned, the larger the radius of the curb the better;

* Trans. Amer. Soc. of Civil Engineers, Vol. 42, p. 7.

but when the gutter is carried to a corner inlet (§ 705), it is inconvenient to construct or cover the gutter if the curved curb intersects the sidewalk, i. e., if the radius of the curved curb is too great. If the pavement has the minimum width, say 18 or 20 feet, the curves of the corner curbs should be made large so that a vehicle may be turned around at the street intersection.

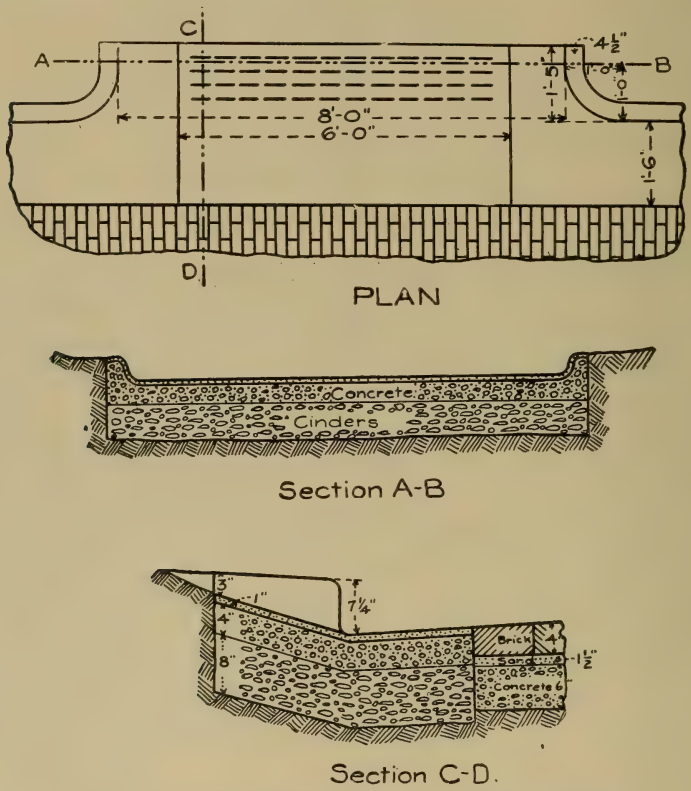

FIG. 141.—CONCRETE CURB AND GUTTER AT PRIVATE DRIVEWAY.

Formerly, when curbs usually were natural stone, the cost of curved sections was considerably more than that of straight pieces; and hence the tendency was to keep the radius as small as possible. But now that concrete curb is very common, curved curbs cost only a little more than straight ones. Formerly, when most of the vehicular traffic was horse-drawn, the chief objection to a short radius was the wear due to wheels striking the curb at the corner; but now on streets having any considerable motor-driven traffic, a corner curb

having a short radius makes it nearly impossible for a motorist to maintain a reasonable rate of speed in turning the corner and at the same time keep his machine on the right side of the street.

The radius varies from 2 to 12 feet, usually from 6 to 8 feet. The curb with a 2-oot radius should not be used at a l, or at least only at driveways to private grounds. A radius of 10 to 12 feet is usually satisfactory; but on boulevards or streets where there is considerable automobile travel, a radius of 16 or even 20 feet is desirable. Several cities have recently spent considerable money to increase the radius of the corner curbs, particularly on main traveled streets and boulevards, to the satisfaction and safety of automobilists.

754. COMBINED CURB AND WALK. In Chicago a concrete walk about 1 foot wide has been constructed along the curb in front of a large apartment building, so as to permit vehicles to stop anywhere along the curb to discharge or receive passengers. Such a walk has been found to be a great convenience.

CHAPTER XV

FOUNDATIONS FOR PAVEMENTS AND STREET-RAILWAY TRACKS

757. The term foundation is sometimes applied to the natural soil upon which an artificial structure rests, and sometimes to the lower portion of the structure itself. The term will be employed here in the latter sense, and the soil under the foundation of the pavement will be referred to as the subgrade.

The foundation of a pavement, as of all other structures, is an important element, although it is more frequently neglected in pavements than in other structures.

One of the most perplexing problems in connection with pavements is the construction and maintenance of a pavement adjoining a street-railway track that is durable and does not interfere unduly with travel. Part of the difficulties are due to the foundation and part to the construction of the pavement adjacent to the rails. The former will be considered in Art. 3 of this Chapter, and the latter in connection with the discussion of the different kinds of pavements.

Art. 1. Preparation of the Subgrade

758. Whatever the form of the pavement or of its foundation, it must rest upon the soil; and since the chief office of the pavement and of its foundation is to distribute the concentrated load of the wheel over an area so great that the natural soil will be able to support it, it is important to increase, as much as practicable, the bearing power of the soil by drainage and by rolling, and thereby to decrease the thickness of pavement required.

759. Drainage. The method of draining the subgrade of a pavement is substantially the same as that of underdraining an earth road—see § 114. The subgrade of a pavement requires underdrainage fully as much as does an earth road, notwithstanding the fact that the former has an impervious roof. The purpose

of the underdrainage is to prevent the surface of saturation from rising so high as to soften the subgrade. Unless the subsoil is very open and porous, it is economical to lay a tile under each edge of the pavement, 2 or 3 feet below the surface of the subgrade. This tile may empty into the surface-water catch basins (§ 703).

760. EARTHWORK. The machinery employed in making excavations and embankments for pavements is practically the same as that used in constructing earth roads—see § 148–57.

In making embankments great care should be taken to compact them solid—see Shrinkage of Earthwork (§ 140), Settlement of Embankments (§ 141), Rol ing Embankments (§ 143), and Stability of Embankment (§ 146). For data on the Cost of Earthwork, see § 164–87.

The excavation for pavements is made by plowing and then removing the earth either with a drag or a wheel scraper (§ 150, 154), or by loading it into wagons or carts with hand-shovels. The subgrade, even though on y a comparatively thin layer is to be removed, has recently been excavated and loaded into wagons with a steam shovel usually of the revolving type; and more recently the excavation has been made with the four-wheel scraper (§ 154) drawn by a steam engine while being loaded. It is usual to specify that no plowing shall be allowed within 2 inches of the subgrade, to prevent the soil below the subgrade from being loosened. If the subgrade is thoroughly rolled, as described later, plowing a little below the finished surface is not a serious matter; but if the subgrade is not subsequently well rolled, the loosening of the soil below the finished surface is very objectionable, since the foundation will then have an uneven hardness.

The subgrade is often finished with pick and shovel, but the work can be done much more economically with the scraping grader (§ 155) or with the surface grader, Fig. 142. The former makes a more uniform surface, and is usually more economical; although the latter is an effective implement. In either case the loosened earth must be hauled away with scrapers or wagons.

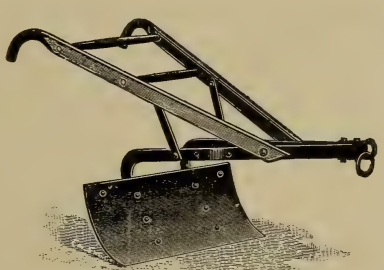

FIG. 142.—SURFACE GRADER.

762. A considerable part of the excavation is often done before the curb is set, but the curb is always set before the subgrade is

finished. The exact position of the subgrade is determined by stretching a string transversely across the street from curb to curb and measuring ordinates similar to those shown in the upper diagram of Fig. 135, page 375. Some contractors pick narrow trenches down to the subgrade at short intervals transversely across the street; while others drive stakes with their tops a specified distance, say 4 or 6 inches, above subgrade, and provide the workmen with a stick of this length with which to measure down from the top of the stake to the subgrade. The former method must be employed when the scraping grader is used. The passage of the grader fills the trench with loose earth, but it is easy to see the relative position of the surface and the bottom of the trench.

763. Rolling the Subgrade. The finished subgrade should be thoroughly rolled to consolidate the surface and also to discover any soft places—particularly over trenches that have not been solidly filled. If the roller reveals a low place, it should be filled with earth and be rolled again. The roller, whatever its weight, should be passed over the subgrade more than once, since the successive passages have something of a kneading action and add to the solidity of the soil. Several passes with a light roller give better results than a few passes with a heavy one. It is well to specify both the weight of the roller and the number of times it is to pass over the road-bed. For some hints applicable in rolling the subgrade, see § 369.

Formerly a horse roller was sometimes used for this purpose; but a steam or rather a self-propelled roller (§ 378) is much better because it is heavier, and, still more important, because with it the street can be rolled transversely. The street is full of trenches made often just before the pavement is laid, in connecting the houses with the sewer, the water, and the gas; and as these trenches run both longitudinally and transversely, it is necessary to run the roller in both directions if the trenches are certain to be solidly filled.

Unless the back-filling of a trench has been unusually well tamped, a roller run transversely over a trench will leave a depression. In most soils, the back-filling will not of itself settle into its former solidity, however long it is left to the action of traffic and to the forces of nature; and whatever the foundation of the pavement, the heavier traffic is nearly certain to cause a settlement over these same trenches, unless the subgrade is well rolled. Traffic consolidates only a thin layer near the surface which is usually removed when the pavement is constructed. Ordinarily, if the subgrade is rolled both longi-

tudinally and transversely with a roller weighing 10 or 12 tons, there will be no settlement of the pavement.

In rolling, if a depression is produced over a trench, it should be filled and then again rolled. If the depression is of considerable depth, it shows that the trench was badly filled or was very deep, or both; and therefore it is wise to re-consolidate the trench. One way of doing this is to make numerous openings through the crust and keep the depression filled with water until the earth in the bottom of the trench has become thoroughly soaked; and then after the ground has dried out below, the roller should again be passed over the surface. The surest way to prevent settlement over trenches is to pack the soil solidly when the trench is first filled. For a discussion of various methods of back-filling, see § 764.

Insufficient tamping in filling trenches or inefficient rolling of trenches is a very common defect in pavement construction, nearly every block presenting one or more such depressions. One of the purposes of a guarantee of the pavement (§ 652) is to secure a thorough consolidation of the soil in the trenches.

764. FILLING TRENCHES. The back-filling of trenches opened to lay water and gas pipes, to make house connection to sewers, etc., so that the road surface shall be restored to its former level and remain so, is a matter of importance on both paved and unpaved roads—particularly the former. The failure to re-fill the trenches properly is a source of annoyance to those who use the unpaved road and of damage to the pavement. It is frequently asserted by those having opportunity for knowing, that the damage to pavements through lack of care in re-filling trenches and re-placing the pavements is greater than the wear due to traffic. No kind of municipal work should be more rigorously inspected than the filling of a trench over which a pavement is to be laid. The nearly universal result of a neglect in this respect is that a pavement built at great expense is disfigured or damaged by settlement, the repair of which will cost many times as much as it would have cost properly to fill the trench originally.

The principal cause of failure is lack of care; but sometimes it is due to a mistake as to the proper method to be employed. A discriminating judgment is required to determine the proper method, and intelligence and faithfulness are necessary in carrying it out. There are several distinct methods used in consolidating the back-filling of trenches.

765. Natural Settlement. A common practice of those having

occasion to make excavations in unpaved streets is to cast back loosely the material taken out, heaping it into an unsightly and annoying ridge over the trench and trusting to travel and the elements to restore the surface to its original level. In nearly pure sand such a ridge may in time settle to the original level, although the damage due to the temporary ridge will generally be much more than the cost of properly filling the trench in the beginning; but as a rule loam or clay loosely put back will not attain a sufficient degree of compactness to make it a safe support for a macadam or other form of pavement. The surface may become very compact and hard; and yet after the removal of a foot or more of soil, ordinarily necessitated by the construction of the pavement, it will be found that the earth in the trench will settle considerably under a roller run transversely over the trench. Even though the surface may support the roller, it is highly probable that ultimately a trench which has been loosely filled will settle and cause a depression in the pavement. This is proved by the numerous depressions in pavements, and also by the fact that when trenches loosely filled are opened years afterwards, it is very common to find open cavities. The promptness with which natural settlement takes place depends upon the climatic conditions and the underdrainage. It is never safe to depend upon natural settlement to secure the proper compacting of the soil in trenches over which a pavement is to be laid, however long the time allowed for the settlement, and much less the few weeks often specified.

766. Flooding. Where the water can be had cheaply, it is a common practice to attempt to consolidate the earth in the trench by flooding or puddling it. If the soil is sand or gravel and is so pervious that the trench will drain out rapidly, thorough flushing will compact the material so that no trouble will be experienced with settlement; but the flushing must be done thoroughly. It is not sufficient to fill the trench nearly full of loose material, and then turn on a gentle stream of water until the trench is full; for trenches thus filled are certain to settle later. The sand or gravel should be added in layers not more than 8 or 10 inches thick, and each layer should be flushed with a stream of water having force enough to wash the finer particles into the voids between the larger ones. Substantially the same result may be accomplished by shoveling the sand or gravel into water 8 or 10 inches deep; but this method will not be effective, if the trench is filled with a scraper or a scraping grader.

However, wherever flushing is effective, tamping would be equally as good and would probably be less expensive, if the cost of the water be considered. As a rule attempting to consolidate trenches by flooding is bad practice.

Neither of the preceding methods of using water should be employed with clay or clayey soils, since flushing prevents rather than assists the consolidation of such soils. In other words, flushing or puddling is useful only with soils which water readily breaks down. If clay is flooded or is deposited in water, the trench is filled with a watery mud that will shrink very much as it dries out and will always be loose and porous. It is well known that a stiff-mud brick which has been moulded under exceedingly heavy pressure will shrink in drying 5 per cent, and with some clays 10 per cent; and of course the thin clay mud in a flooded trench will shrink very much more than this.

767. Tamping. Except in the case of comparatively clean sand and gravel, back-filling can be thoroughly done only by tamping; and to make this method successful it is necessary (1) that the material shall be moist enough to be plastic, but neither too wet nor too dry, (2) that it shall be deposited in layers not more than 3 or 4 inches thick, and (3) that each layer shall be thoroughly tamped. To secure thorough tamping the relative numbers of tampers and shovelers is sometimes specified; but this alone is ineffectual since there is a natural tendency for the tampers to work less energetically than the shovelers, and besides more labor is required to tamp the soil around the pipe than higher up.

The amount of ramming required will vary with the character and condition of the soil. Clay and hard pan should be moistened before being tamped, while clean sand or clean gravel may be tamped dry. The tamping can be most effectively done with a comparatively small light rammer or tamper, since the effect of the blow is transmitted to a greater depth, while a broad heavy rammer consolidates the surface only. A tamper weighing 5 or 6 lb. is better than one weighing 20 or 25 lb., the lighter one being lifted higher and giving less fatigue than the heavy one. It is important to remember that any amount of ramming will affect only a comparatively thin layer.

Obviously back-filling should not be attempted when the material is frozen, since subsequent settlement is then sure to take place.

768. To prevent disturbing the surface of a pavement, plumbers, gas fitters, etc., are sometimes given permission to tunnel under

the pavement to make their connections. This practice is never justifiable on account both of the excessive cost and of the impossibility of effectively filling the tunnel, owing to the limited space in which the work must be done. In nearly every case a depression occurs sooner or later over the tunnel.

769. Replacing All the Material. The result to be obtained in filling a trench is that the material in the trench shall have the same compactness as the soil around it; and therefore some contend that the only proper way is to put back all the material taken out. In a majority of cases this procedure will secure reasonably good results; but under certain conditions it will fail. For example, the water pipe or sewer may occupy a large proportion of the volume of the trench, and consequently of necessity there will be a considerable excess of earth. Again, putting back all the earth does not insure the restoration of the original surface nor certainly prevent subsequent settlement. It has been shown that soil when taken from its natural place and compacted in an embankment will shrink from 8 to 15 per cent (see § 140), and will probably subsequently settle 2 or 3 per cent and possibly 10 to 25 per cent (see § 141). Consequently with a deep trench containing a small pipe, it is possible to tamp the earth back so solidly as not to have enough to restore the surface; or it is possible to put all the soil back by tamping the lower portion of the trench solidly and the upper portion loosely, and still considerable settlement take place. Therefore the specification to re-place all of the material, must have a careful and intelligent supervision to insure good results.

In the past it has not been the custom to fill trenches in such a manner as to prevent settlement; and therefore if the best results are to be insisted upon, the specifications should clearly reveal that fact, for contractors in bidding on work do so on the understanding that the work is to be done in at least approximately the usual manner, and any attempt to have it done in any better way, which was not clearly understood from the beginning, is likely to cause friction and irritation, and possibly finally to result in failure.

770. Re-filling with Sand or Concrete. On account of the difficulty of getting trenches in clay or loam filled so that there will be no settlement, it has been proposed to require the trench to be filled with clean sand or gravel. It is not known that this method has ever been tried. It would probably be effective, but usually its cost would be prohibitive.

In at least a few cases trenches have been filled with a fair quality of hydraulic cement concrete. The expense for the concrete was not justifiable, since it was much greater than that required thoroughly to tamp the back-filling.

Sometimes municipal authorities are lax in inspecting the filling of trenches, owing to the belief that the concrete foundation will hold up the pavement even though the material in the trench may settle; but this is bad practice, since the ordinary thickness of concrete is not designed to act as a bridge, and besides if it is thick enough to bear up over trenches it is needlessly thick elsewhere. With the usual thickness of concrete foundations, a depression is almost certain to occur if the material in the trench settles; and hence the only safe rule is to have the trenches completely and compactly filled.

ART. 2. THE CONSTRUCTION

772. In some cases a pavement has been laid directly upon the natural soil; but this is possible only with brick, stone-block, or wood-block pavements laid upon clean sand or gravel. This practice is wise only with light travel. Formerly in Cleveland, Ohio, many brick pavements were laid directly upon the native sand.

Stone-block and brick pavements were formerly laid upon a layer of gravel or broken stone; but the decline in price of hydraulic cement has made it economical to substitute concrete for the layer of gravel or broken stone, owing to the labor and care required to secure a bed of uniform density and smooth surface.

A layer of portland cement concrete is now the nearly universal foundation for street pavements.

773. PORTLAND-CEMENT CONCRETE FOUNDATION. This is by far the most common foundation for pavements. The advantages of such a foundation are: 1. It gives a smooth uniform surface upon which to lay the pavement. 2. It prevents the surface water from percolating to the subgrade. 3. By its thickness and resistance to flexure, it distributes the concentrated load over a considerable area of the subgrade. 4. Concrete acts as a bridge to support the pavement in case of a settlement of the subgrade. 5. Being impervious to water and a non-conductor of heat, concrete protects water and gas pipes from freezing.

774. The Materials. For a discussion of the cement, the sand, and the gravel or broken stone as ingredients for concrete, see Art. 1 of Chapter VII.

775. Thickness. The thickness of the concrete varies from 4 to 8 inches, but is usually 6 inches. There is considerable diversity of opinion as to the sufficiency of a 6-inch concrete foundation, particularly since the introduction of motor trucks. Examples are frequently cited of the failure of a concrete foundation, particularly where a motor truck or heavily loaded wagon has broken through a pavement; and the conclusion is drawn that the concrete slab was too thin. However, making the foundation thicker is not necessarily the economical remedy. The foundation may have failed for one or more of the following reasons: 1. Insufficient rolling of the subgrade. 2. Insufficient consolidation of back-filling in trenches. 3. The use of natural cement in the concrete, which is weaker than portland cement and lacks uniformity. 4. Improper proportions, insufficient mixing, or inadequate curing of the concrete. As a rule insufficient attention is given to each of these items. 5. Passage of loads over the concrete before it had sufficiently set. 6. Vibrations due to weak construction of street railway track, which shatter the concrete and allow water to get under the foundation which upon freezing still further cracks the concrete.

On the other hand, many examples can be cited where a 4-inch concrete base has successfully carried a heavy traffic. It is probable that a well-constructed slab 4 inches thick laid on a well-consolidated subgrade is stronger than a foundation of poor concrete 8 inches thick laid upon an insufficiently rolled subgrade.*

776. In view of the rapid introduction of the motor truck and the consequent crushing of some pavement foundations, it is probable that concrete pavement foundations should be improved in quality or increased in thickness—or perhaps both. The question of improving the quality depends upon the relative cost of materials and labor; and the advisability of increasing the thickness can be determined only by a discriminating study of the experience with a particular thickness.

777. The thickness of concrete roads (§ 447) gives some indication as to the required thickness of concrete pavement foundations, although the former are ordinarily more carefully constructed than the latter. The thickness of concrete roads is usually about 6 inches, and is seldom more than 6 inches at the sides and 8 inches at the center, the excess thickness at the center being to provide for reduc-

* For a discussion of this subject, pro and con, see *Engineering News*, Vol. 72 (1914), p. 176, 367, 558, and 1033; and Vol. 75 (1916), p. 1097.

tion by wear. The wearing coat adds thickness to the pavement, which distributes the wheel-load over a greater area of the subgrade, and some kinds of wearing surfaces also give additional beam strength to the pavement as a whole. For example, the binder and wearing coat of a sheet asphalt pavement adds $2\frac{1}{2}$ or 3 inches in thickness, and gives considerable additional beam strength. Again, a portland-cement grouted brick wearing-coat has been found to give so much additional beam strength that the total thickness of the pavement has been greatly reduced in recent years (see § 1028-30).

778. It has been proposed to limit motor trucks to certain streets, rather than build all pavement foundations heavy enough to carry such loads. There would be some justice in such a requirement, but the enforcement of it would be difficult.

779. The Proportions. For a discussion of the theory of proportioning concrete, see § 417–24, Chapter VII—Concrete Roads.

The proportions of the concrete for a pavement foundation is usually determined arbitrarily without much, if any, reference to the gradation of the coarse and fine aggregate. The proportions and sizes of the aggregate specified by a number of important cities whose specifications happened to be at hand, are as follows:

Proportions	Sand	Stone
$1 : 1\frac{1}{2} : 2\frac{1}{2}$	$\frac{1}{4}''$ to fine	$\frac{1}{4}''$ to $1''$
$1 : 1\frac{1}{2} : 3$	$\frac{1}{4}$ to fine	$\frac{1}{4}$ to $1\frac{1}{2}$
$1 : 2 : 3$	$\frac{1}{4}$ to fine	$\frac{1}{4}$ to $1\frac{1}{2}$
$1 : 2\frac{1}{2} : 4$	$\frac{1}{4}$ to fine	$\frac{1}{4}$ to $1\frac{1}{2}$
$1 : 3 : 5$	$\frac{1}{4}$ to fine	$\frac{1}{2}$ to 2
$1 : 3 : 6$	$\frac{1}{4}$ to fine	$\frac{1}{2}$ to 2

The last proportions seem to be much the most used. It may be that with the aggregates ordinarily employed in each case, the proportions specified will give a good concrete; but the quality of the concrete can not be foretold from the above specifications. To secure the best results the proportions should be determined, or at least tested, by a sieve analysis (see § 422); and to make the specifications really significant both the proportions and the gradation of the aggregates should be stated.

For the proportions used in concrete roads see § 444. However, it is not customary to use as rich a mixture in concrete pavement-foundations as in concrete wearing-surfaces; and under ordinary conditions, it is not necessary.

780. Mixing. All that is said in § 451–58 concerning the mixing of concrete for concrete roads, applies to concrete for pavement foundations.

781. Placing. If the subgrade has been rutted up by ordinary travel or in the delivery of paving materials, the surface should be restored; and if the surface has been much disturbed, the subgrade should be again rolled. The ridges thrown up at the sides of a wheel track may materially weaken the concrete foundation. Under ordinary circumstances the subgrade should be sprinkled just before the concrete is laid. This will prevent the dry subgrade from absorbing moisture from the concrete, and will also prevent its drying out too fast.

It is important that the surface of the concrete shall conform to the required grade and crown. The thickness may be indicated by grade stakes set every 4 or 5 feet. Some engineers require the concrete to be struck off with a template which may run upon the curbs or upon screeds carefully placed for that purpose.

The edge of the concrete should form a straight line from curb to to curb perpendicular to the line of the street.

782. No contraction joints are provided in concrete pavement foundations as in concrete roads, since the latter are not as much exposed to temperature changes as the former.

783. Finishing. The concrete should be tamped to consolidate it. The wetter the concrete, the less the tamping needed; and usually there is very little tamping. Many engineers claim that the concrete is ordinarily unduly weak because it is mixed unduly wet. If the concrete is not mixed too wet, the proper tamping or ramming of the concrete will consolidate it and fill the voids, and add materially to its strength. Until recently it was the usual custom to finish the concrete foundation by light tamping; and often the surface was unduly rough. In defense of this practice it was claimed that the rough concrete prevented the shifting of an asphalt pavement; and that with brick, stone-block, and wood-block pavements the roughness of the concrete did no harm, as the cushion layer gave a smooth surface upon which to place the pavement. In neither case is the claim valid. A sheet asphalt pavement upon such a foundation will creep and form waves or humps because of the difference in compression due to its unequal thickness; and it has been conclusively established that the thinner the cushion course the better for any brick pavement (see § 971) or block pavement (see § 1096). The utmost roughening of the surface of a concrete base of

sheet asphalt pavement should be that produced by a slight raking while the concrete is fresh; and for all other kinds of pavements, the smoother the finish the better.

Sometimes the surface of the concrete is grouted, that is, a rich mortar is poured upon the surface and swept over it to level up any depression and to fill up any honeycombing. Sometimes the surface is broomed without the pouring on of any grout, the surplus mortar being swept from one part of the surface to level up depressions and to fill up, or rather hide, honeycombing. The term slushing is sometimes applied to each of these processes. No such method of finishing the surface should ever be permitted; although in extreme cases concrete made of fine stone in the stated proportions may be used to level up depressions.

Some engineers claim that the surface of a concrete base should be floated to secure a uniform smooth surface upon which to lay asphalt-block or wood-block pavements. With a brick pavement the same result is accomplished in another way (see § 982).

Not infrequently loose stones are left on the upper surface of the concrete foundation while laying the binder course of a sheet asphalt pavement or the cushion course of a brick or block pavement. Such a practice is inexcusable, since the labor to remove such stones is slight, and since they have a seriously destructive effect upon the wearing coat.

784. Curing. In building concrete roads, it is nearly universal after the concrete is laid to protect it during curing by covering it with canvas, or damp earth, or a sheet of water (see § 464); but in constructing concrete pavement-foundations, it is quite unusual to take any such precautions, and consequently the concrete is frequently seriously damaged by drying out too rapidly in hot or windy weather, or by exposure to low temperature.

The period during which the concrete base should be allowed to harden will depend upon the weather conditions and the kind of pavement to be laid upon it, or rather upon the method of delivering the subsequent paving materials. Teaming over the concrete in building the remainder of the pavement should never be permitted in less than 10 to 15 days, depending upon the weather; and the pavement should not be open to heavy loads in less than 15 to 21 days from the time the concrete foundation was laid. The pressure to shorten this time is often very great, particularly on a business street.

785. Cost of Concrete Foundations. *Materials.* The cost of

materials varies with the locality and the conditions of the markets (see § 425–27); and hence it is unwise to cite examples except as in § 790. When the prices are known, estimates may be easily prepared by the use of Table 28, page 237.

786. *Labor.* Formerly concrete for pavement foundations was mixed by hand; but in recent years it is almost always mixed by machine.

787. Hand Mixing: The following data on the labor-cost of hand-mixing are out of date as to the method of mixing and also as to the cost of labor; but as the price of labor is stated, these data may be useful in making estimates when hand mixing is to be employed.

In a small western city the average cost to the contractor of mixing and laying a thickness of 6 inches of concrete during two years was about 7 cents per square yard, for 1 part cement, 2 parts sand, and 4 parts broken stone, turned six times exclusive of casting into place. With gravel instead of broken stone the cost was about 6 cents per square yard; and with four turnings instead of six, the cost was about half a cent less than the prices above. All the mixing was done with shovels. The wages of common laborers was $1.50 for 10 hours.

In a large western city the average cost to various contractors of mixing and laying a thickness of 6 inches of concrete was $5\frac{1}{2}$ cents per square yard. The mixing was done with hoes, the specifications requiring that the concrete should be mixed until each particle of the stone was completely covered with mortar. The wages of common laborers was $1.50 for 10 hours.

778. The following example * gives the distribution of the labor of laying a 6-inch concrete pavement foundation, in hours per square yard:

Items.	Hours per Sq. Yd.
4 men filling barrows with sand and stone	0.15
10 men wheeling, mixing, and shoveling to place (3 or 4 steps)	0.37
2 men ramming	0.07
1 water boy, equivalent in common labor	0.01
1 foreman, equivalent in common labor	0.06
Total hours per square yard	0.67

The sand and stone were dumped in the street upon boards, and were hauled in wheel-barrows about 40 feet to the mixing boards.

* *Engineering News*, Vol. 46 (1901), p. 424.

The mortar was turned three, and the stone three or four times. Two gangs under separate foremen worked side by side in the same street.

The same correspondent gives another example which required 0.56 hour per sq. yd., in which case the mortar was turned only once and the stone twice, water being used in abundance.

The cost of labor in mixing and laying concrete is often 8 or 9 cents a square yard. For the most economical work the sand and stone should be deposited in ridges on the subgrade near the middle of the street; and if they are piled on the parking, the cost will be considerably greater than above.

789. For data on cost of hand-mixed concrete for concrete roads, see § 374.

790. *Total Cost.* The total cost of a concrete pavement-foundation laid in a city in the Central States in 1916 was as follows:

Items	Cu. Yd.	Sq. Yd.
Subgrade:		
Rough grading,—1,504 cu. yd.	$0.298	
Surfacing and rolling 3,380 sq. yd., and cleaning up	0.090	$0.040
Miscellaneous expense	0.036	0.009
Total, exclusive of superintendence, depreciation on machinery, administration	$0.424	
Concrete Base:		
Cement at $1.48 per bbl. on job, net	$1.365	$0.227
Sand at $1.40 per cu. yd. on job	0.731	0.122
Gravel at $1.50 per cu. yd. on job	0.934	0.156
Coal and water	0.035	0.006
Labor	0.336	0.056
Miscellaneous expense	0.038	0.017
Total, exclusive of superintendence, depreciation on machinery, administration	$3.439	$0.584

The pavement was 34 feet wide. The proportions of the concrete were 1 : 3 : 5; and the thickness was 6 inches. The concrete was mixed in a one-bag mixer. The loss on bags was 1 per cent. The wages of common labor was 20 cents per hour; the engine runner on the concrete mixer, 30 cents per hour; and a team, wagon, and driver, 50 cents per hour.

791. Old Macadam Foundation. It not infrequently happens that a high-class pavement is to replace a water-bound gravel or macadam surface, in which case it may be economical to use the old pavement as a foundation for the new. This form of foundation has

been discussed in connection with the construction of concrete roads. The possibility of utilizing an old gravel or macadam road as a foundation occurs more frequently with a narrow concrete or brick rural road than with a comparatively wide street pavement. For a consideration of the difficulties encountered and of the methods to be employed, see § 437.

792. BITUMINOUS CONCRETE FOUNDATION. Bituminous-cement concrete has some advantages over hydraulic-cement concrete for pavement foundations. 1. The bituminous concrete does not require any time for curing and hardening; and consequently the wearing coat may be laid as soon as the foundation is completed, which may be a decided advantage on a busy thoroughfare. 2. The bituminous concrete is more flexible than hydraulic concrete, and hence is not so likely to crack. 3. If the wearing surface of a pavement is made with a bituminous cement, a bituminous concrete foundation is advantageous, since then the whole pavement can be made with one kind of equipment and organization. 4. A bituminous wearing coat will adhere better to a bituminous concrete base than to a hydraulic concrete base. 5. The use of a bituminous concrete base makes unnecessary the binder course of a sheet asphalt pavement; but on the other hand, with a bituminous concrete base it is practically impossible to remove the bituminous wearing coat without materially damaging the foundation. However, it is claimed that by the use of a surface heater (Fig. 161, page 450), repairs can be made in the asphalt wearing coat without damage to the bituminous foundation. For a further discussion of a bituminous concrete foundation for sheet or monolithic asphalt pavements, see § 806–08.

793. The question of economy depends upon the local prices of bituminous and hydraulic cement. At present the price of bituminous cement is substantially 1 cent per pound, while that of portland cement is about $2.40 for 376 pounds or about 0.66 cent per pound. The specific gravity of bituminous cement (a paste) is about 1, while that of hydraulic cement paste is about 2; and hence the prices per unit of volume are about 1 to 1.3, or in other words, at present prices the hydraulic cement concrete is about 30 per cent the more expensive. Or to put it another way, when portland cement costs more than $1.88 per barrel, there is a possibility that bituminous concrete may be the cheaper. There has not been sufficient experience with bituminous concrete to determine with any considerable accuracy the cost of mixing and laying it.

794. Bituminous concrete pavement foundations were used in a

number of cities in this country from about 1880 to 1895, owing probably to the high price of hydraulic cement, particularly portland cement; and some of these foundations are still giving satisfaction.

Tar concrete has been used in England for pavement foundations for many years.

795. The strength of a bituminous concrete foundation will depend upon the kind and quality of the bituminous cement used; and no such foundation is as strong as one made with equal care of portland cement.

ART. 3. FOUNDATIONS OF STREET-RAILWAY TRACKS

796. One of the most common failures of pavements is adjacent to the rails of a street-car track; and is often due to the defective foundation of the track. In a general way these failures are due to the vertical vibrations of the rails, which pounds the foundation to pieces and also breaks the bond between the rail and the pavement, thus permitting water to enter which on freezing heaves the pavement. The vibrations of the rail may be due to the deflection of the rail or to the compression of the ties and foundation or to both.

The design and usually also the construction of the foundation of the track is a function of the engineer of the street railway, while the construction and maintenance of the pavement adjoining the track is under the direction of the city engineer; but to secure reasonably satisfactory results requires the co-operation of both interests.*

797. FOUNDATION. The foundation may be of gravel, or broken stone or concrete. With gravel ballast it is practically impossible to prevent the rail from working up and down owing to the movement of the ballast and the difficulty of tamping the ties uniformly. Broken stone gives better results than gravel, but is far from satisfactory. Gravel or broken-stone ballast is reasonably satisfactory for railways in the open country upon a private right-of-way; but the case is very different on a city street where all have equal rights and which must be paved and maintained for general public use. It is generally conceded that the track, at least in streets having any considerable amount of heavy traffic, should rest upon a concrete foundation.

* For an instructive article on the relations of the two interests involved and a discussion thereon by several engineers, see "A Suggested Change of Policy for Maintaining the Pavement adjoining the Railway," by N. S. Sprague, Chief Engineer of Bureau of Engineering, Pittsburgh, Pa., in Proc. Amer. Soc. Municipal Improvements, 1915, p. 271–77 and 277–82.

There is great variety in the form of the concrete foundation. It may be a slab of uniform thickness extending under the track, or the thickness may be increased longitudinally under each rail or transversely under each tie. An important advantage of the first form of construction over either of the others is that it eliminates trenches in the subgrade, which can not be rolled and which are likely to be partially filled with loose earth by the breaking down of the edges of the trench by workmen. With the trench construction the depth of the concrete is not likely to be uniform, and is likely to be laid on loose earth instead of a compacted subgrade.

798. Examples. Fig. 143 shows the two types of track foundations recommended by the Committee on Way of the American

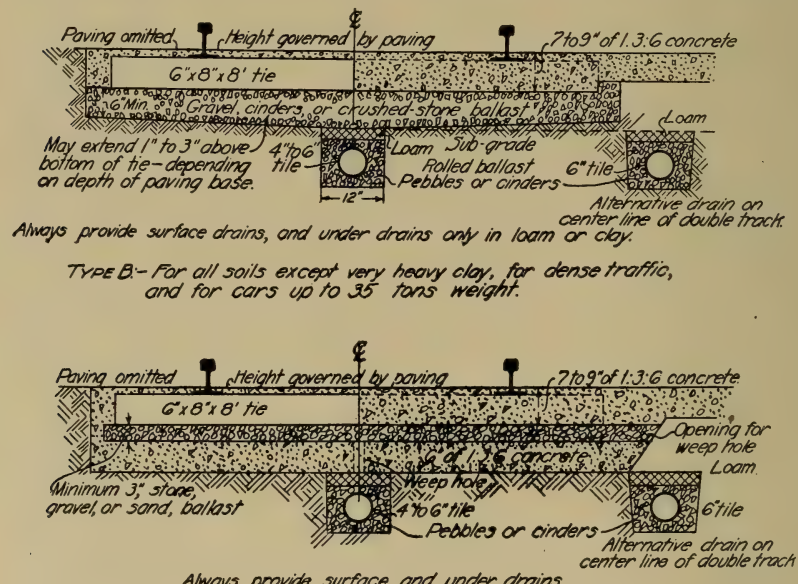

FIG. 143.—TRACK FOUNDATIONS FOR PAVED STREETS.

Electric Railway Engineering Association.* Notice that in both examples the rail is the T pattern; but as far as shown in Fig. 143, there is no difference between the T and the grooved rail. For track foundations with a grooved rail, see Fig. 159, page 442, Fig. 160, page, 443, and Fig. 196, page 540; and for two track-

* Proceedings Amer. Elect. Ry. Eng'g Assoc., 1915, p. 471.

foundations with T rails, see Fig. 197, page 540. Notice that the lower half of the last shows a concrete beam under each rail.

For a cross section of a street-railway track in a sheet asphalt pavement, see Fig. 159 and 160, page 442–43; in a brick pavement, see Fig. 196 and 197, page 540; and in a stone-block pavement, see Fig. 218, page 587.

799. THE TIES. The ties are either wood or steel, the former being the more common. Wood ties have a long life when embedded in concrete, especially if treated by some preservative process;

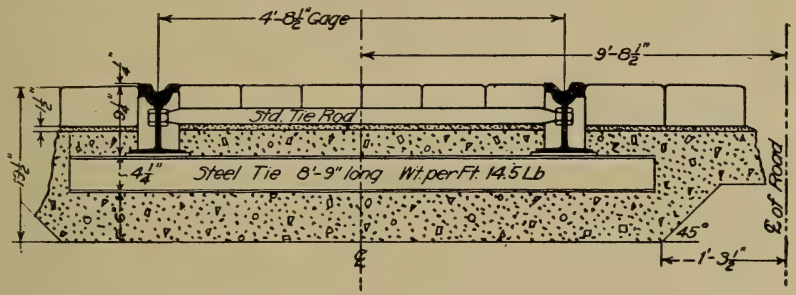

FIG. 144.—STEEL-TIE STREET-RAILWAY TRACK.

and there is an increasing use of treated wood ties. For illustrations showing track with wood ties, see Fig. 143.

Steel ties have been used to only a comparatively small extent. For a cross section of the track with steel tie used in Chicago, see Fig. 144. The construction shown in Fig. 144 has been found to be objectionable on account of the difficulty of paving around and over the tie-rod between the rails. Concrete ties have been used in street-railway track only a little, if at all.

800. THE RAILS. The rails are one of three types, viz.: the flat-top, the grooved top, and the T section. The flat-top rail, which has been almost abandoned, was very destructive of the pavement, as steel-tired vehicles frequently ran with one wheel on one of the railway rails, the result being that the wheel on the pavement wore a rut. Where the flat-top rail is in use, it is not uncommon to find at least two ruts on each side of each track—one made by a broad-gage wagon running with its left wheels on the left rail and its right wheel to the right of the right rail, one made by any wagon running with its left wheel on the right rail; and if the wagons are of two different gages, the last position will cause two narrow ruts close together or one wide one. For illustrations of track construction using the T section, see Fig. 143, page 408, and Fig. 197, page 540; and for illustrations

showing a grooved top, see Fig. 159 and 160, page 442–43, and Fig. 196, page 540.

801. THE PAVING. In selecting the material for the pavement adjacent to the rails, consideration should be given to the amount and character of the vehicular traffic and to the relative cost and life of the several classes of pavements. The preference of the members of the American Electric Railway Engineering Association is as follows: granite-block, Medina sandstone-block, creosoted wood-block, vitrified brick, asphalt-block, sheet asphalt, bituminous concrete, bituminous macadam, water-bound macadam. The railway company usually prefers granite block because of its durability, and possibly also because its roughness deters vehicles from using the railway area.

The precautions to be taken in laying the different paving materials adjacent to a street-railway track will be considered in the subsequent chapter treating the respective kind of pavement.

For cross sections of a sheet asphalt pavement adjacent to a street railway track, see Fig. 159 and 160, page 442–43; for a cross section of a brick pavement and a street-railway track, see Fig. 196 and 197, page 540.

CHAPTER XVI

ASPHALT PAVEMENTS

802. For a discussion of asphalt, its sources, its characteristics, the methods of testing it, and specifications for asphalt for different purposes, see Art. 1 of Chapter VIII—Bituminous Road Materials.

Asphalt is used in three forms of pavements, viz.: sheet asphalt, asphalt concrete, and asphalt block. The wearing coat of the first consists essentially of an asphalt mortar, i. e., a mixture of sand and asphalt cement; and that of the second is an asphalt concrete, i. e., a mixture of broken stone and asphalt cement. Both of these forms of asphalt pavements are mixed and laid hot. The wearing coat of an asphalt block pavement consists of blocks of asphalt concrete moulded hot and laid when cold. The first form is by far the most common; but the second, of which bitulithic pavement is a form, although a comparatively recent development, is quite widely used (§ 636).

Each of these forms will be treated in a separate article.

Art. 1. Sheet Asphalt Pavements

803. A sheet or monolithic asphalt pavement consists primarily of (1) a wearing coat $1\frac{1}{2}$ to 2 inches thick composed of asphalt paving cement mixed with sand; (2) a binder course 1 to $1\frac{1}{2}$ inches

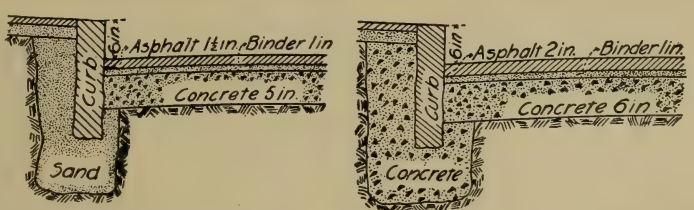

Fig. 145.—Two Forms of Sheet Asphalt Pavements.

thick, composed of broken stone and asphalt cement; and (3) a foundation of hydraulic-cement concrete—see Fig. 145.

In this country when the term asphalt pavement is used the above form is usually intended. The term sheet or monolithic pavement is

not distinctive, since rock asphalt also is laid as a continuous sheet; but no confusion is likely to result, since in this country the term sheet is commonly used to distinguish the monolithic form from the asphalt-block pavement, and since in Europe only one form of asphalt pavement is used, monolithic natural rock. In contra-distinction to a pavement made of natural asphalt limestone or sandstone, the above pavement could with some propriety be called an artificial asphalt pavement, or the wearing coat could with still more propriety be called an artificial asphalt paving compound; but the distinction is not important, since the sheet asphalt pavement is laid almost exclusively in this country and the rock asphalt almost exclusively in Europe.

804. HISTORICAL. The first artificial sheet asphalt pavement in this country was laid in Newark, N. J., in front of the city hall in 1870. In 1873 a small piece was laid on Fifth Avenue, New York City, opposite the Worth Monument. A few other experimental sections were laid; but the first test on a large scale was in 1876 on Pennsylvania Avenue, in Washington, D. C. Preceding 1882, outside of Washington, D. C., there were not more than half a dozen streets in this country paved with any form of asphalt; but since that date, asphalt pavements have increased rapidly, and now hundreds of miles of it are in use on the streets of American cities. The following statistics show the rapid growth of this industry: In this country in 1880 there were 300,000 square yards of sheet asphalt pavements; in 1885, 1,800,000; in 1890, 8,100,000; in 1895, 21,500,000; in 1900, 38,000,000; in 1909, 83,227,000. In Europe in 1900, the latest data available, there were only about 3,000,000 square yards of asphalt pavements of all kinds.

In 1909 in the United States according to the data on page 320, about one fifth of all pavements were sheet asphalt; and if water-bound gravel and macadam be excluded, about one third of all durable pavements were sheet asphalt.

Asphalt pavements can be adapted to a wide range of temperature, and are in extensive use from Winnepeg to Panama—from the far north to the tropics.

805. THE FOUNDATION. For a description of the method of preparing the subgrade, see Art. 1 of Chapter XV,—Pavement Foundations.

Since the sheet-asphalt wearing surface has little or no power in itself to act as a bridge, it is essential that it be placed upon a firm foundation; and consequently it is nearly always placed upon a bed

of hydraulic-cement concrete, which formerly was sometimes made with natural cement but is now always made with portland cement. For heavy city traffic, the concrete is usually 6 inches thick; but for light traffic, it is sometimes only 4 inches thick. For a discussion of the proper thickness of a portland-cement concrete foundation and the method of laying it, see § 773–84.

It is necessary that the concrete be thoroughly dry before the asphalt mixture is laid upon it, as the generation of steam caused by placing the hot material upon a damp foundation will produce blistering and possibly disintegration of the wearing coat. This is a matter that needs close attention in laying an asphalt pavement. To dry the foundation after a rain or during damp weather, fine hot sand is sometimes spread over the concrete and then swept off; but this method is expensive and not very effective, and besides there is liability that enough sand will be left upon the foundation to interfere with the adhesion of the asphalt.

806. Bituminous Concrete Foundation. It is claimed, with apparent justification, that asphalt pavements usually fail because of a defective foundation rather than because of inherent defects in the surface coat or of the wearing away of its materials; and some claim that better results would be obtained by the use of a bituminous concrete foundation instead of a hydraulic concrete base.

For a general discussion of a bituminous concrete base, see § 792–95.

807. It is claimed that the bituminous concrete base is superior to the portland-cement concrete foundation in four particulars, as follows:

1. There is a lack of frictional resistance between the wearing coat and the portland-cement foundation, which gives rise to one of the most common failures of sheet asphalt pavements. The pressure and impact of wheels upon the surface of the pavement produce a horizontal component which causes the asphalt to creep and form waves or humps, which make the pavement uncomfortable in use particularly by automobiles, and these humps are difficult to remove. A slight roughening of the top of the concrete base is insufficient to resist this lateral movement; and an excessive roughening is harmful rather than otherwise, since a difference in thickness of the asphalt sheet causes a difference in compression and a consequent lateral movement. It is claimed that the asphalt wearing coat will unite more firmly with a bituminous concrete foundation than with a hydraulic concrete base.

2. There is a lack of adhesion between the asphalt mixture and the portland-cement concrete, which gives rise to a second common form of failure, since there is insufficient adhesion between the asphalt and the concrete to resist the action of water at the surface of contact of the two materials. If the concrete foundation is not very dense, water will be drawn to the top of it by capillary action; and the effect of water on the under side of the asphalt tends to disintegrate the bond between the asphalt and the hydraulic concrete. Further, since the asphalt sheet prevents evaporation, the upper surface of a hydraulic concrete foundation is usually moist; and hence any frost action tends still further to destroy the bond between the two materials. It is claimed that with equal care and equally suitable proportions, bituminous concrete will be more waterproof than hydraulic concrete; but the experience with bituminous concrete under modern methods of preparing, mixing and laying has been insufficient to establish such a conclusion.

3. A third objection urged against a hydraulic-concrete foundation is that cracks in the asphalt sheet are caused by temperature and setting cracks in the foundation. This is probably true; but the wise remedy is to properly cure the concrete (§ 784).

4. Another argument for the superiority of a bituminous base over a hydraulic one is that the former is more elastic; and hence absorbs the effect of the impact of traffic, and prevents the lateral flow of the wearing coat. This effect can not be very great; and it is of doubtful value, since the chief advantage of a monolithic asphalt wearing surface is its inherent stability.

808. On the other hand, the portland-cement concrete base possesses the following points of superiority over a bituminous concrete base.

1. A portland-cement concrete base is stronger, and hence will better distribute concentrated loads, will better bridge over soft spots in the subgrade, and will better resist the tendency to crack due to unequal settlement.

2. Ordinarily it is cheaper.

3. There is less difficulty in making repairs in the asphalt surface.

809. Other Foundations. A sheet asphalt wearing surface has been laid on old cobble-stone, brick, and stone-block pavements; but with varying success. The conditions necessary for success seem to be: 1. The old pavement must be firm and solid. 2. The old pavement must have a fairly uniform surface so that the asphalt

coat will have a nearly uniform thickness, say not less than 1 or $1\frac{1}{2}$ inches nor more than 2 or $2\frac{1}{2}$ inches. 3. The old pavement must be perfectly clean and absolutely dry. 4. Of course, the asphalt wearing course must be made of suitable material, have appropriate consistency, and be properly applied.

Apparently, failures in laying sheet asphalt on an old pavement have been more common than successes.

810. BINDER COURSE. In the past there has been considerable trouble in getting an asphalt wearing coat to adhere to a hydraulic-cement foundation, and various expedients have been tried; but at present one of two methods is always employed, viz.: either apply an asphalt paint coat to the foundation, or lay a binder course.

811. Paint Coat. A paint coat consists of an asphalt cement fluxed with naphtha or benzine, which is applied with a brush or squeegee to the portland-cement concrete. It is essential that the concrete shall have a fairly smooth surface; that the base shall be perfectly dry; that the paint coat shall be bright and glossy, but not sticky; and that it shall be kept clean until the wearing coat is applied.

This method of construction is applicable only to a light-traffic street or road where low first cost is necessary. The method has been used to a considerable extent by cities in California.*

812. Kinds of Binder Course. The binder course is a layer about $1\frac{1}{2}$ inches thick of broken stone cemented together with asphaltic paving cement (§ 818) and rolled in place while hot. It is often called simply the binder; but this is likely to cause confusion, since the term binder usually refers to the cementing material in a water-bound gravel or macadam road, or in a bituminous macadam or concrete, etc.

There are two forms of binder course, the open and the closed. The former does not contain as much cement, i. e., is not as rich, as the latter; and its aggregate is not as carefully graded. The open binder is used to secure a cheaper pavement; and will not endure under medium or heavy traffic. The closed binder has greater inherent stability, and hence is preferable for medium or heavy traffic.

813. Specifications for Open Binder. *Broken Stone.* The broken stone should be clean, and have a compact texture and uniform grain.

* *California Highways*, January, 1915.

For medium or heavy traffic the stone should be strong and break with sharp edges and corners.

The broken stone should have the following gradation on screens having circular opening: "All of the material shall pass a $1\frac{1}{4}$-inch screen; and not more than 10 per cent, nor less than 1 per cent, shall be retained on a 1-inch screen; and not more than 10 per cent, nor less than 3 per cent, shall pass a $\frac{1}{4}$-inch screen."*

814. *Sand.* It is not customary to use sand in an open binder; and it is often specified that the stone shall not contain more than a certain amount of fine material. However, the more fine material (sand or screenings) in the binder the more compact and more desirable it is, provided the fine material is not more than enough to fill the voids. But the greater the amount of fine material, the more the bitumen required to coat all the particles; and consequently the more expensive the binder. For the latter reason, it is not customary to use much fine material in an open binder; and usually no fine material is used except that in the stone.

815. *Asphalt Cement.* The asphalt cement is of the grade stated in § 542. The amount of cement should be sufficient to coat the fragments of stone and bind them together reasonably well; and will depend upon the kind and gradation of the stone and the richness desired. With trap or hard limestone graded as above, only 3 or 4 per cent of pure bitumen is used; and with a soft limestone 4 or 5 per cent is common. There should not be so much cement that it will run off the stone, but there should be enough to give a bright glossy coat to the stone.

After being rolled the surface of the binder course will be porous or open, and hence the name given to it.

816. Specifications for Closed Binder. *Broken Stone.* The quality of the broken stone should be the same as for open binder (§ 815).

The gradation of the broken stone should be as follows, as determined with screens having circular openings: "95 per cent of the binder aggregate shall pass a screen having circular openings equal to three quarters of the thickness of the binder course to be laid; and the smallest dimensions of the remaining 5 per cent shall not exceed the thickness of the binder course. The aggregate shall have the following composition: 20 to 50 per cent shall pass a $\frac{1}{2}$-inch

* Report of Committee of the Amer. Soc. of C. E., Proc. Vol. 42 (1916), p. 1626; or page 5 of Specifications for Sheet Asphalt Pavements of Amer. Soc. of Municipal Improvements, adopted October 14, 1915.

screen and be retained on a 10-mesh screen; and 15 to 35 per cent shall pass a 10-mesh screen."*

817. *Sand.* The chief difference between an open and a closed binder is the greater density and stability of the latter. A closed binder should contain enough screenings or sand to fill the voids in the coarse material; and the gradation of the coarse and fine aggregate should be such as to give a minimum percentage of voids, and consequently require a minimum amount of asphalt cement. Apparently not much attention has been given to the quantity or gradation of the fine material, i. e., sand and stone screenings, for the binder course; and certainly no specifications for the fine material have been published. The quantities in Table 38, page 418, are from actual practice in one of the largest cities in this country.

818. *Asphalt Cement.* The object in using a closed binder course is to secure maximum stability, and hence enough asphalt cement must be used to coat all the fragments of the aggregate and fill all the voids. If the aggregate contains considerable fine sand and dust, the stability will be greater but more asphalt cement will be required. With very carefully graded aggregate 3.5 per cent of asphalt cement will give a very stable mixture; but if the gradation is not so good 7 per cent may be required. There should be enough asphalt cement to give stability; but an excess may be very harmful, as it will likely collect in pools in the truck while being taken to the street and appear in spots in the binder course, from which it will be drawn up on a hot day into the wearing coat and soften it. A uniformly distributed excess is less dangerous on a light-traffic street than on a heavy-traffic one, since in the former the wearing surface is likely to lose its volatile matter and crack, while a rich binder will slowly enrich the wearing surface.

The asphalt cement should be softer than that in the wearing coat, because the binder is more open than the wearing coat, and hence more of the lighter oils are volatilized in the mixing, and also because the softer cement makes a mixture less liable to rupture. In ordinary practice the cement for the binder has a penetration 20 or more greater than that for the wearing coat.

819. Amount of Bitumen in Binder. To illustrate the method of determining the per cent of bitumen in a particular mixture,

* Report of Committee of the Amer. Soc. of C. E., Proc. Vol. 42 (1916), p. 1629; or Specifications for Sheet Asphalt Pavements of Amer. Soc. of Municipal Improvements, adopted October 14, 1915.

assume that the composition of the asphalt cement and the binder course are as stated in Table 38. The pure bitumen in the bitumi-

TABLE 38

COMPOSITION OF BINDER COURSE

ASPHALT CEMENT		MATERIAL FOR BINDER COURSE			BITUMEN IN BINDER
Ingredients	Per Cent	Ingredients	Lb.	Per Cent	
Mexican asphalt...	40	Asphalt cement.....	122	7	
Trinidad asphalt...	40	Sand.....	438	25	
Indian flux.....	20	Broken stone.....	1 190	68	
Total.....	100	One batch or boxful.....	1 750	100	5.8%

nous materials is as follows: Mexican asphalt, 99.6 per cent; Trinidad asphalt, 56.0 per cent; and Indian flux, 99.6 per cent. Then the bitumen in the asphalt cement is:

Mexican asphalt..... $40 \times 99.6 = 39.84\%$
Trinidad asphalt..... $40 \times 56.0 = 22.40\%$
Indian flux..... $20 \times 99.6 = 19.92\%$

Total Bitumen in Asphalt Cement..... $= 82.16\%$

Total Bitumen in Binder Course..... $= 82.16 \times 7 = 5.8\ \%$

It is impossible from the above computations to determine whether or not the stated amount of bitumen will fill the voids in the mineral matter. That could be determined accurately only by direct test, but could be determined approximately from a knowledge of the gradation of the mineral matter and a comparison of it with the composition of standard binder mixtures. The method of determining the amount of bitumen and the gradation of the mineral matter necessary to give a binder course of maximum stability is exactly the same as for the wearing course (§ 825 et seq.), and hence will not be discussed here.

820. Mixing Binder Course. The aggregate and the asphalt cement should be heated separately, the exact temperature of each depending mainly upon the character of the asphalt cement. The cement is usually heated to a temperature between 120° C. (250° F.) and 177° C. (350° F.); and the aggregate is heated between 107° C. (225° F.) and 177° C. (350° F.).

The aggregate and the cement should be thoroughly mixed by

machinery until a homogeneous mixture is obtained in which all the particles of the aggregate are covered with cement.

The mixing is done in a box in which revolves two axles each carrying a series of oblique paddles set spirally—see Fig. 146.

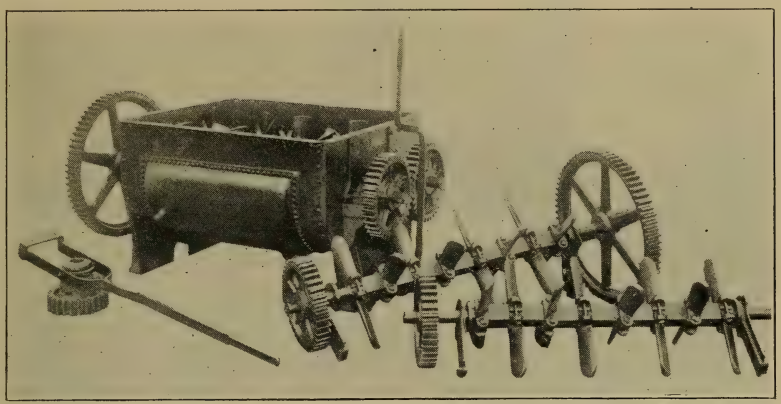

FIG. 146.—MACHINE FOR MIXING ASPHALT BINDER.

The mixture is discharged through a sliding door in the bottom of the box. The capacity of mixers vary from 1000 to 2000 pounds.

Fig. 147, page 420, shows a complete semi-portable asphalt mixing plant. On the left is the boiler; and on the right is the elevator for the fine and coarse aggregate, and the drum for drying them. Behind the boiler is the asphalt-heating tank or kettle; and behind the sand-drying drum is the mixer with sand-storage bins above it.

Fig. 148, page 421, shows a portable asphalt-mixing plant. Similar plants are mounted upon one and sometimes upon two steam-railroad cars. In the larger cities are fixed plants which consist of quite a group of buildings.

821. Laying Binder Course. The binder course should be transported to the street in wagons or trucks covered with canvas or tarpaulin; and when delivered should have a temperature between 93° and 163° C. (200° and 325° F.), the temperature between these limits being regulated according to the temperature of the atmosphere and the ease with which the binder course can be spread. The temperature of the binder on the street should be no greater than is necessary to permit the mixture to be easily spread.

The stone should be covered with a bright glossy coat of asphalt

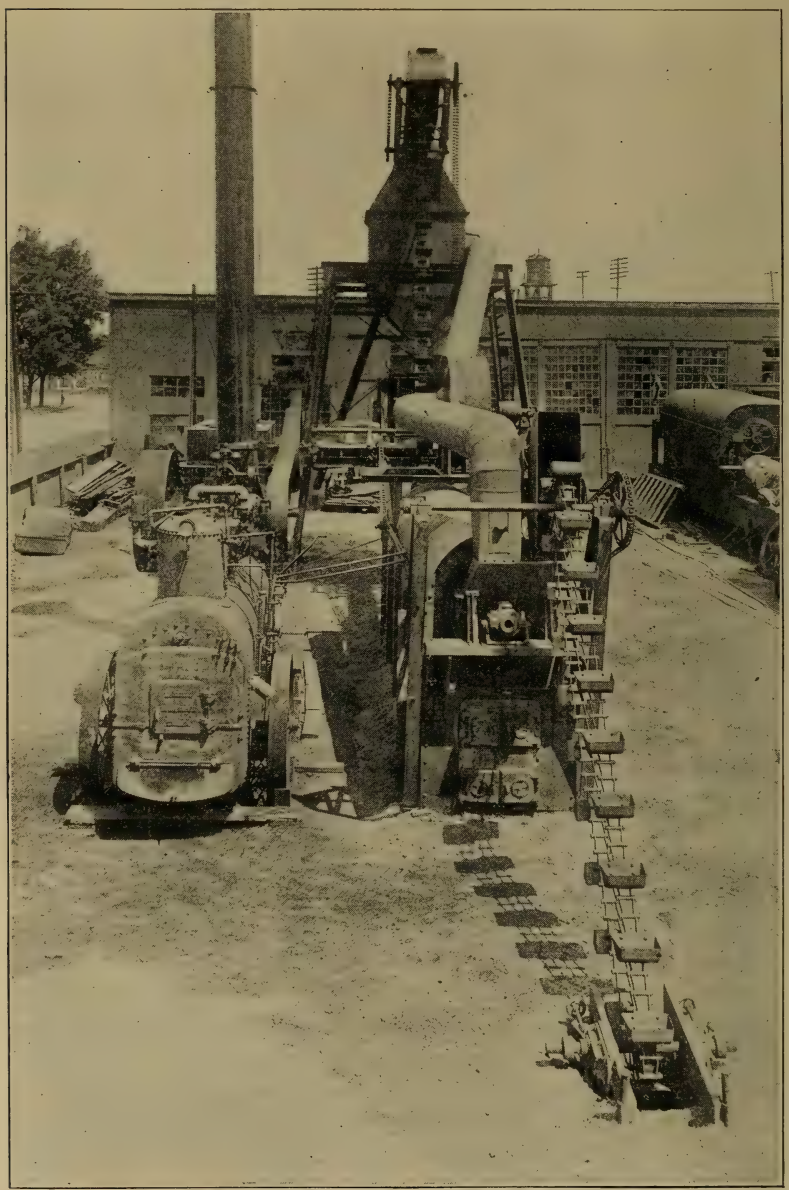

FIG. 147.—SEMI-PORTABLE ASPHALT MIXING PLANT.

cement, as otherwise it will have no coherence. On the other hand, there should be no excess of cement, as is shown by its running from the bottom of the truck or by too great richness of the bottom of the load. If the stone was heated too hot, the cement may run off the stone at the top of the load and accumulate at the bottom, in which case the surface of the load will appear dull and dead.

On arrival on the street the mixture should be dumped upon the foundation at such distance from where it is to be spread as to

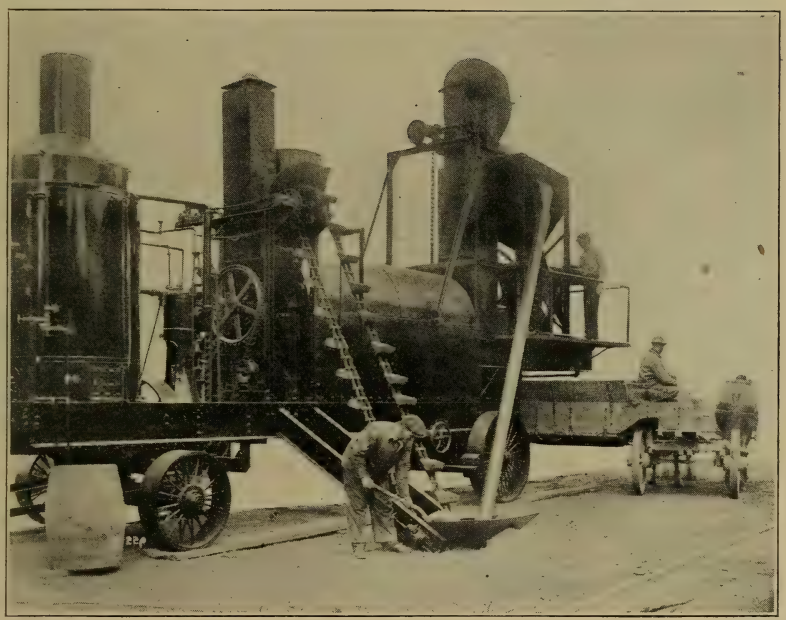

FIG. 148.—PORTABLE ASPHALT MIXING PLANT.

require that all of the material shall be moved from where dumped. This is necessary to secure a uniform thickness after rolling, since the portion at the bottom of the pile is considerably compressed by the fall and the weight of the incumbent mass, and hence if it is not moved the binder course after being rolled will be thicker at this point than elsewhere.

The binder is first roughly shoveled into place, and then is leveled off with rakes or shovels. An open binder may be leveled with hot iron rakes having long tines; but if a closed binder is employed, the spreading should be done with a shovel or the back of a rake, as the use of the tines will bring the larger stones to the surface and produce

segregation. Fig. 149 shows the spreading of the binder course. Notice that the binder is dumped on a steel plate from which it is shoveled into place.

The binder course may be allowed to cool somewhat before being rolled, for if it is too hot when rolled it is likely to stick to the roller and also be pushed out of place. The rolling should be done with a self-propelled tandem roller weighing 5 to 7 tons, giving a pressure

FIG. 149.—SPREADING THE BINDER COURSE.

of not less than 200 pounds per lineal inch of tread. The object of the rolling is a kneading action as well as a compression, and hence many passes of a light roller are better than a few passes of a heavy roller.

After rolling the surface should be of uniform density; and particularly there should be no spots containing an excess of asphalt cement, since on a hot day the excess is likely to be drawn up into the wearing coat and soften it.

822. After the rolling of the binder course is completed, the wearing coat (§ 825) should be applied at once, while the binder is clean and hot; or it should at least be added during the same day for fear the binder may become dirty and dusty. This is necessary to secure the maximum bond between the binder and the wearing coat; and if this is not done, the binder course should be protected from mud and excessive dust.

823. Thickness of Binder Course. The proper thickness of the

binder course depends upon the amount of the traffic. For light traffic the thickness is usually 1 inch after being rolled and for medium traffic is $1\frac{1}{2}$ inches, while for very heavy traffic it is sometimes 2 inches. For data on the thickness of binder course in various cities, see Table 46, page 453.

The compression by rolling is usually about 40 per cent. The area that a given weight of the binder course will cover will depend upon the hardness and gradation of the stone, upon the consistency and temperature of the asphaltic cement, and upon the degree of compression.

824. The thickness to which the compressed mixture should be spread to give the specified thickness can be determined either by computation or by trial.

1. To compute the area to be covered by a given weight, first determine the specific gravity of the compressed binder course, and then compute the area that a given weight should cover to give the required thickness after rolling.

2. Lay a given weight on a known area, roll it, and then measure the thickness by probing at several points with a dull pointed awl, being careful that the awl penetrates to the foundation. After a few trials the exact area to be covered by a stated weight to give the desired thickness, can be accurately found.

825. WEARING COAT. The wearing coat consists of sand, and fine mineral dust or filler, and asphalt cement. The sand and filler are often referred to as the mineral aggregate.

826. The Sand. The sand is a very important element in a sheet asphalt pavement, since it constitutes at least three fourths of the wearing coat. The sand should consist of hard and durable grains. It should be free from vegetable matter, and should not contain much clay or loam; although a small amount of these, if not closely adhering to the grains, will act as a filler and do no harm. However, a small amount of clayey material adhering to the grains is highly objectionable, since in passing through the heating drum or dryer it is likely to be burned onto the grains to such an extent as not to be removed in the mixer and consequently the bitumen will not adhere well to the sand.

The gradation of the sand, i. e., the relative proportions of grains of different sizes, is the chief characteristic to be considered; occasionally, however, a sand is found which for some unknown reason, perhaps the shape of the grains or character of the surface, proves to be unsuitable for sheet asphalt pavements.

827. *Gradation of Sand.* Until comparatively recently but little attention was given to the gradation of the sand; but it is now known that this is one of the most important elements in the construction of a sheet asphalt pavement. Table 39 shows the grading of the sand used for the wearing coat of sheet asphalt pavements in a number of cities before the importance of this element was appreciated. The last line of the table shows the grading now believed to be the best attainable. The data in this table are mainly interesting as showing a possible reason for the unsatisfactory service of some sheet asphalt pavements.

TABLE 39

FORMER GRADING OF SAND FOR SHEET ASPHALT PAVEMENTS*

Ref. No.	City.	Per Cent Passing Sieve No.								Total Per Cent.
		200	100	80	50	40	30	20	10	
1	Boston, 1899:	6	13	14	31	20	10	4	2	100
2	Buffalo:									
	bank, fine	31	39	21	8	1	..	..	.	100
	lake, coarse	1	6	10	41	19	15	5	3	100
3	Chicago, 1896:									
	fine	10	68	15	5	2	...	....	...	100
	medium	2	15	17	52	9	2	2	1	100
4	Louisville:									
	river	2	1	4	53	25	10	3	2	100
	bar	32	33	13	18	3	1	....	...	100
5	Milwaukee:									
	coarse beach	0	1	2	36	32	17	9	3	100
	White Fish Bay	2	25	29	36	4	3	1	...	100
6	Omaha	2	19	19	41	12	3	2	2	100
7	St. Louis, 1897:									
	coarse	0	1	1	48	46	3	1	0	100
	fine	14	26	14	38	6	2	....	...	100
	river, coarse	2	4	22	28	19	10	10	5	100
	fine	17	40	30	10	1	1•	1	...	100
8	Richardson's Ideal:†									
	mineral aggregate	14.5	14.5	14.5	26.2	12.3	9.0	5.6	3.4	100
	sand proper	0.0	17.0	17.0	30.0	13.0	10.0	8.0	5.0	100

* Richardson's Modern Sheet Asphalt Pavement, p. 85.
† *Ibid.*, p. 332.

The ideal grading for sand for a sheet asphalt was obtained by analyzing pavements that had given the best service; and has been abundantly tested in practice for more than twenty years. Unfortunately it is not often that a natural sand can be found which approximates the ideal grading; and therefore an artificial mixture must be prepared by screening the sand into several lots excluding one or more of the lots, and then remixing the remainder, or by com-

bining portions of different sands. Unless the available natural sand is nearly ideal, the securing of the best grading will entail considerable expense; and in this case it may be wiser to accept a grading only approximating the ideal. Table 40 shows the ideal grading for heavy traffic and also two permissible gradings.

TABLE 40

STANDARD GRADINGS FOR SAND FOR SHEET ASPHALT PAVEMENTS

Grade of of Sand.	Passing Sieve No.	Richardson's Gradings.* Ideal for Heavy Traffic.		Richardson's Gradings.* Permissible for Light Traffic.	Forrest's Permissible Grading.†
Dust	200	00.0		00.0	00.0
Fine	100	17.0%			
	80	17.0			
		Total	34%	26.0%	20 to 30%
Medium	50	30.0%		30.0	
	40	13.0		13.0	
		Total	43%	43.0%	not over 40%
Coarse	30	10.0%			
	20	8.0			
	10	5.0			
		Total	23%	30.0%	20 to 30%
Very coarse	8	0.0		0.0	not over 10%
		Total 100	100	100	100

* Richardson's Asphalt Construction for Pavements and Highways, 1913, p. 29.

† C. N. Forrest, Chief Chemist, Barber Asphalt Paving Co., in private letter to the author dated August 17, 1917.

Notice that the aggregate for heavy traffic is finer than that for light traffic. The reason for this is as follows: Large pieces of aggregate will be fractured sooner or later by the passage over them of heavy loads; and when this occurs there are two surfaces which are not cemented together. This condition permits a movement and a grinding action, and also allows the entrance of water; and thus two extremely destructive agents are set to work.

Table 41, page 426, shows the grading of sands used recently by the Barber Asphalt Paving Co., in pavements in various cities. These data are instructive as showing the degree of agreement of the gradings of the best available sands with the standards stated in

Table 40, and are also a valuable guide in selecting a sand for use in a pavement.

TABLE 41

AVERAGE GRADING OF SANDS RECENTLY USED IN SHEET ASPHALT PAVEMENTS *

City.	PER CENT PASSING SIEVE NO.										Passing No. 10.
	Fine Sand.			Medium Sand.			Coarse Sand.				
	100	80	Total	50	40	Total	30	20	10	Total	
Boston	13.2	15.8	29.0	42.0	15.8	57.8	6.6	4.0	2.6	13.2	
Buffalo	16.7	12.5	29.3	34.7	9.7	44.4	5.5	4.2	9.7	19.4	7
Chicago	20.6	21.9	42.5	43.6	6.4	50.0	2.5	2.5	2.5	7.5	
Kansas City	26.3	19.2	45.5	23.4	8.9	32.3	8.9	8.9	4.4	22.2	
Louisville	16.4	11.0	27.4	35.6	17.8	53.4	9.6	5.5	4.1	19.2	
New York	14.6	13.3	27.9	37.5	17.3	54.8	9.3	5.3	2.7	17.3	
Omaha	9.2	17.2	26.4	51.1	7.9	59.0	5.3	5.3	4.0	14.6	
St. Louis	20.5	19.2	39.7	37.1	8.2	45.3	6.8	5.5	2.7	15.0	
Richardson's Ideal	17.0	17.0	34.0	30.0	13.0	43.0	10.0	8.0	5.0	23.0	

* Compiled from Richardson's Modern Sheet Asphalt Pavement, p. 331.

828. The Filler. The filler is fine mineral matter mixed with the sand to fill the voids, and thus reduce the amount of asphalt required, and also to make the wearing coat more waterproof and less plastic. Further, the use of a filler permits the use of a softer asphalt cement and thus makes the wearing coat less liable to internal displacement in summer and less brittle in winter.

The filler is usually either pulverized limestone or portland cement, generally the former. Portland cement is preferable for heavy traffic or where the asphalt surface is subject to the action of water. The heavier the filler per unit of volume the better, since this usually indicates greater density; and the denser the filler, the denser and more stable the wearing coat. The valuable part of the filler is the impalpable dust which is much finer than the particles just passing a 200-mesh sieve. "A good filler should contain at least 60 per cent by weight of actual dust, and preferably 70 per cent."

The amount of material in the wearing coat passing a 200-mesh sieve varies from 10 to 20 per cent, according to the grading of the sand, but usually from 12 to 16—see § 835. Less filler is required with Trinidad asphalt than other kinds, since it naturally contains about 44 per cent of finely divided mineral matter.

829. ASPHALT CEMENT. The method of preparing the asphalt cement has been described in § 530; and specifications for it are found in § 542.

The amount of asphalt cement in the wearing coat should be sufficient to coat every particle of mineral matter and fill all the voids, but should not be enough to make the mixture too susceptible to pressure and temperature changes. If too much asphalt cement is used, the sand grains will be readily displaced among themselves, and the wearing coat will push out of place. If too little cement is used, the surface will crack and is liable to be displaced because of lack of solidity. The finer the mineral aggregate, the greater the amount of cement required for stability. Too much dust in the aggregate causes the mixture to be mushy.

830. Amount of Cement. The amount of asphalt cement to be used in any particular case depends upon the gradation of the sand and the filler, and to some extent is a matter of judgment and experience; but there are four tests that are guides in determining the best proportions of sand, filler, and cement for the wearing coat. These tests are the paper-pat test, the impact test, and the determination of the density and the absorptive power of the compressed mixture.

831. *Paper-pat Test.* This test is made as follows: Secure a sheet of manila paper having a smooth surface, crease it down the middle, and lay it opened out on a smooth firm *wood* surface, not stone or metal, which would cool the mixture too rapidly. With a wooden paddle having a blade 3 or 4 inches wide and about $\frac{1}{2}$ inch thick, tapering to an edge, take a paddleful of the hot mixture, being careful to get a representative sample. Note the temperature of the mixture. Drop the mixture sidewise from the paddle on to the paper, and fold the paper over the mixture. With a block of wood press the surface of the mixture down until it is flat, and then strike it five or six blows with the block until the pat is about half an inch thick. Open the paper, and the stain upon the paper indicates the amount of bitumen in the mixture. Fig. 150–53, page 428–31, show four progressive characteristic stains.* Fig. 150 indicates a mixture in which there is a considerable deficiency of bitumen, Fig. 151 a slight deficiency of bitumen, Fig. 152 a mixture having the proper amount, and Fig. 153 an excess of bitumen.

In interpreting the character of the stain consideration must be given to the temperature of the sample and to the kind of asphalt. The sample must be taken and the stain made when the temperature of the mixture is such that the asphalt is quite liquid. If the mix-

* By courtesy of D. T. Pierce, Executive Assistant, Barber Asphalt Paving Co.

FIG. 150.—LIGHT STAIN.

FIG. 151.—MEDIUM STAIN.

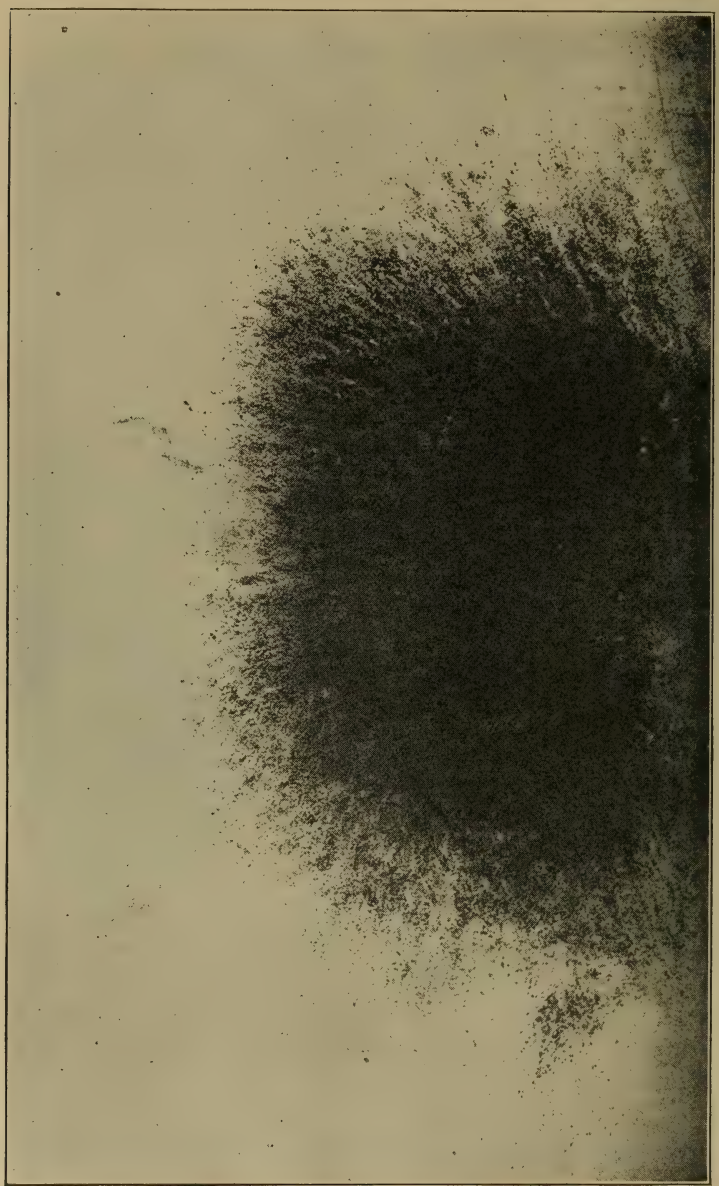

FIG. 152.—STRONG STAIN.

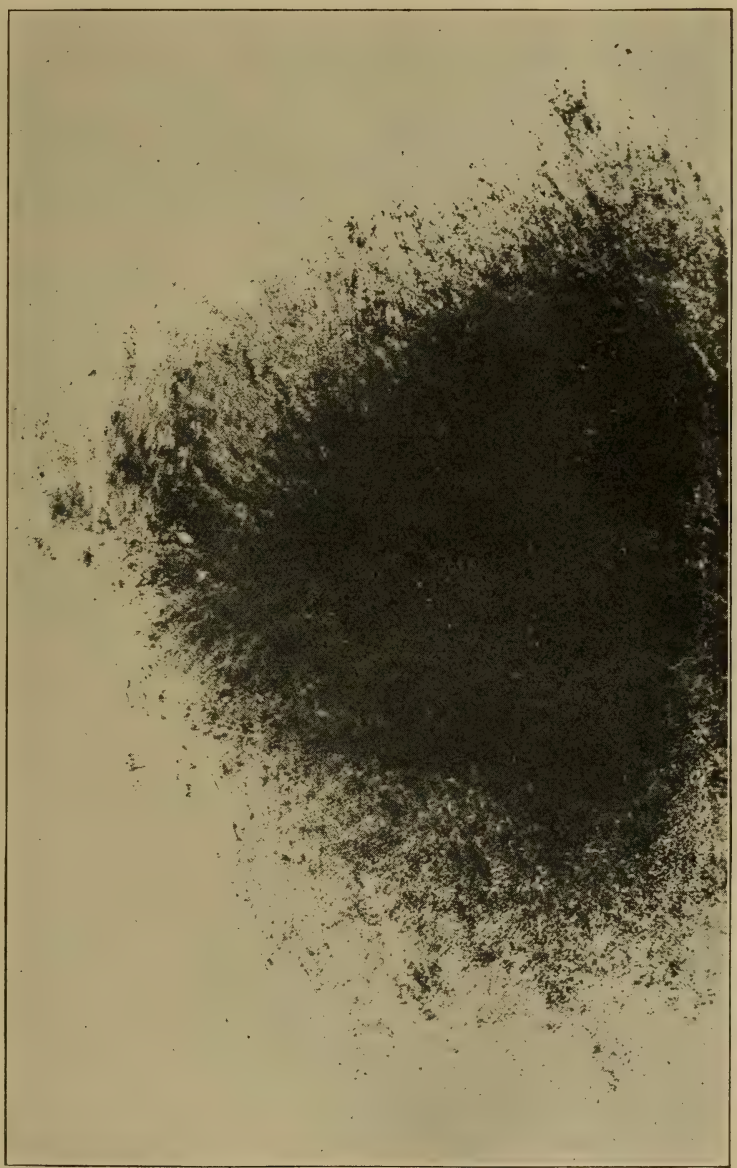

FIG. 153.—HEAVY STAIN.

ture is too cold, the test is of no value; and if the mixture is too hot, the stain will be stronger than for the proper temperature. Further, the test is more valuable for Trinidad asphalt than for other kinds of asphalt, since the latter are more susceptible to temperature changes.

The appearance of the surface of the hot pat is nearly as instructive as that of the stain on the paper. If the mixture is unbalanced in any way, the surface will have a greasy appearance, which may be due to an excess of either bitumen or filler; but the cause of the greasiness can be determined only by trial.

832. *Density.* Another method of testing the correctness of the proportions of the wearing coat is to determine the density, or specific gravity, of the compressed mixture. A cylindrical test specimen $1\frac{1}{4}$ inch in diameter and about 1 inch high, is moulded while hot under standard pressure. The specific gravity of the specimen is then determined either by weighing it in air and in water, or by weighing it in air and measuring its volume.

The following example illustrates the method of making this test.*

The customary mixture in parts by weight is:

Sand	75 per cent
Dust or filler	10 " "
Trinidad asphalt cement	15 " "
Total	100 " "

The specific gravity of the sand is 2.65, the limestone dust 2.60, and the asphalt cement 1.25. The volumes of the materials in the mixture are:

Sand	75 ÷ 2.65 = 28.30	units of volume	= 64.10%
Limestone dust	10 ÷ 2.60 = 3.85	" " "	= 8.72
Asphalt cement	15 ÷ 1.25 = 12.00	" " "	= 27.18
Total	44.15	" " "	= 100.00%

If the mass is compressed so as to exclude all the entrained air, i. e., so that all the voids in the mineral aggregate are filled with asphalt cement, then the specific gravity of the mixture would be:

Sand	64.1% × 2.66 = 1.699
Limestone dust	8.7% × 2.60 = .226
Asphalt cement	27.2% × 1.25 = .340
Ultimate specific gravity	= 2.265

The specific gravity of the specimen should be at least 2.20, and is usually not over 2.22. If portland cement is used as a filler instead of limestone dust, the specific gravity will be about 0.02 higher,

* Richardson's Modern Asphalt Pavement, p. 581.

since the specific gravity of portland cement is about 3.10. The greater the proportion of asphalt, the less the specific gravity.

If the specific gravity of the specimen is 2.22, the voids are: $(2.265-2.22)\div 2.265=2$ per cent.

Pavements having the standard grading, after being rolled, have within 1 or 2 per cent of the ultimate specific gravity; but some pavements laid without regard to the best gradation, have specific gravities as low as 1.90, and have not given reasonably satisfactory service.

833. *Absorptive Power.* The denser the mixture and the larger the percentage of bitumen it contains, the more resistant it will be to the action of water; hence a determination of the absorptive power of the compressed mixture gives valuable information concerning the correctness of the proposed proportions, particularly if the pavement is to be laid in a humid atmosphere.

The absorptive power is determined by moulding a cylindrical specimen as in determining the density (§ 832), weighing it, suspending it in water, and then weighing it at intervals. The gain in weight is the water absorbed; and the absorption per unit of area may then be computed. Table 42 shows the results with two mixtures, the first containing coarse sand and too little filler, and the second being Richardson's ideal mixture.

TABLE 42

ABSORPTION OF CYLINDERS OF WEARING COAT *

Pounds per Square Yard

Interval	WASHINGTON MIXTURE, 1893		IDEAL MIXTURE, 1904.	
	Trinidad Asphalt.	Bermudez Asphalt.	Trinidad Asphalt.	Bermudez Asphalt.
Seven days	0.314	0.063	0.080	0.094
Fourteen days	0.434	0.194	0.093	0.093
Twenty-eight days	0.502	0.306	0.107	0.104

834. *Impact Test.* A cylindrical test piece is moulded as in making the density test (§ 832), and then it is subjected to successive blows of the dropping weight of the impact machine.† The dropping weight or hammer weighs 2 kilograms (4.40 lb.); and the height of fall is 1 centimeter for the first blow, and an increase of 1 centimeter for each successive blow until the test piece fails. The

* Richardson's Modern Asphalt Pavements, p. 468.

† Bulletin No. 44, Office of Public Roads, U. S. Department of Agriculture, June 10, 1912, p. 9–11.

number of blows required to produce rupture is assumed to represent the toughness of the specimen. The number of blows required to produce failure will depend upon the consistency of the asphalt cement and upon the temperature of the specimen at the time of testing. The best mixtures at a temperature of 78° F. require from 20 to 30 blows to produce rupture.

835. Proportion from Practice. Table 43 shows the grading of the wearing coat of sheet asphalt pavements laid in 1916 and 1917 by different contractors in a number of cities,* and also Richardson's ideal proportions† and Forrest's permissible composition.‡

TABLE 43

PROPORTIONS FOR SHEET ASPHALT PAVEMENTS

Laid in 1916 and 1917

Ref. No.	Locality.		Bitumen, per Cent.	Per Cent Passing Sieve No.								
	State.	City.		200	100	80	50	40	30	20	10	4
1	Massachusetts	Boston	11.4	12.6	17.0	7.0	21.0	10.0		5.0	6.0	2.0
2	"	Roxbury	10.1	12.9	12.0	6.0	17.0	11.0	8.0	9.0	10.0	1.0
3	New York	New York	10.4	17.1	13.6		47.0		11.0	12.3		1.5
4	North Carolina	Kingston	10.5	11.6	9.4	7.4	30.7	10.1	5.3	5.9	7.6	1.5
5	Ohio	Hamilton	10.2	16.1	7.7	3.9	18.9	12.1	13.1	10.4	5.8	1.8
6	"	Newark	10.1	10.3	14.2	16.2	30.9	4.3	2.9	3.1	5.1	2.9
7	South Carolina	Sumter	10.0	11.0	13.0	10.0	25.0	12.0	10.0	7.0	2.0	
8	Richardson's Ideal, at least		10.0	10.0	10.0	20.0	24.0	10.0	8.0	5.0	3.0	
9	Forrest's Permissible		9–11	10–12	15–25		least possible		15–25			

836. The specifications for sheet asphalt pavements adopted by the American Society of Municipal Improvements on October 14, 1915, contain the following requirements for the composition of the wearing coat:

Bitumen	9.5 to 13.5%	
Passing 200 mesh	not less than 10%	total not less than 25%
Passing 80 mesh	10 to 35%	
Passing 50 mesh	4 to 35%	total 15 to 50%
Passing 40 mesh	4 to 25%	
Passing 30 mesh	4 to 20%	total 10 to 35%
Passing 20 mesh	4 to 12%	
Passing 10 mesh	2 to 8%	
Passing 8 mesh	0 to 5%	

"The minimum amount of bitumen shall be used only in mixtures containing the minimum passing the 80 mesh; and the percentage of bitumen must increase as the amount passing the 80 mesh increases."

* By courtesy of D. T. Pierce, Executive Assistant, Barber Asphalt Paving Co., in letter to the author under date of Sept. 14, 1917.

† Richardson's Modern Sheet Asphalt Pavement, p. 326.

‡ C. N. Forrest, Chief Chemist, Barber Asphalt Paving Co., in letter to the author dated August 17, 1917.

837. Percentage of Bitumen. Notice that Table 43 shows the percentage of bitumen; while the wearing coat is a mixture of asphalt cement, filler and sand. To compute the percentage of bitumen in the wearing coat proceed as follows: Assume that the asphalt cement and the wearing coat have the compositions stated in Table 44.

TABLE 44

COMPOSITION OF WEARING COAT

ASPHALT CEMENT		WEARING COAT		
Ingredients	Per Cent.	Ingredients	Lb.	Per Cent.
Mexican asphalt	40	Asphalt cement	285	14.2
Trinidad asphalt	40	Limestone dust	300	15.0
Indian flux	20	Sand	1 415	70.8
Total	100	Total	2 000	100.0

The bitumen in the bituminous materials is as follows: Mexican asphalt, 99.6 per cent; Trinidad asphalt, 56.0 per cent; and Indian flux, 99.6 per cent. Then the pure bitumen in the asphaltic cement may be computed as follows:

Mexican asphalt $40 \times 99.6 = 39.84$ per cent
Trinidad asphalt $40 \times 56.0 = 22.40$ " "
Indian flux $20 \times 99.6 = 19.92$ " "

Total bitumen in asphalt cement $= 82.16$

Hence the total bitumen in the wearing coat is $82.16 \times 14.02 = 11.7$ per cent.

838. Mixing the Wearing Coat. The sand and the asphalt cement should be heated separately. The sand should have a temperature between 275 and 400° F. (135–205° C.), and the asphalt cement from 250 to 350° F. (121–177° C.). The exact temperature in any case depends upon the asphalt used; and the temperature between these limits is to be adopted to suit the particular asphalt. A temperature which is appropriate for one asphalt may harden another too much; or a temperature which makes one asphalt so fluid that it separates from the aggregate, may make another asphalt so stiff that it can not be properly spread and rolled. The sand, filler and asphalt cement for each batch or mixerful should be carefully and separately weighed, and then be dumped into the mixer.

The mixing is done in a machine like that shown in Fig. 146, page 419. The mixing should be very thorough, and be continued until the mass is homogeneous and each particle of aggregate is covered with asphalt. The mixing usually requires 1 to $1\frac{1}{2}$ minutes.

839. Laying the Wearing Coat. The mixture for the wearing coat should be brought to the street in wagons or trucks covered with canvas, at a temperature of 230 to 350° F. (110–177° C.). The temperature within the above limits is regulated according to the kind of asphalt, the temperature of the air, and the ease with which the mixture is spread.

The top of the binding course should be perfectly dry when the wearing coat is laid, to prevent the top course from being separated from the course below by the formation of steam. Asphalt should not be laid in cold weather, since the paving mixture may become chilled between the mixing plant and the street, and particularly when it comes in contact with the cold foundation.

The mixture should be dumped outside of the area on which it is to be spread, so that it shall all be moved in being put into place and thus secure an even distribution of the material. This is very important, since great care must be exercised to prevent depressions or elevations in the finished surfaces, as the impact due to such spots is likely to cause the wearing coat to be pushed out of place. The mixture is thrown into place with hot shovels after which it is uniformly spread with hot rakes. The depth to which the mixture is to be spread is regulated by chalk lines on the curb, by the length of the teeth of the rake, and sometimes by rods supported on feet of a length sufficient to bring the top of the rod to the level of the uncompacted mixture. The compression in rolling varies with the richness of the mixture, the leaner mixtures compressing most; and is usually from three tenths to four tenths.

Fig. 154 shows the spreading of the wearing course of a pavement on Fifth Avenue, New York City.

840. Immediately after being spread the wearing coat should be composed by rolling or tamping. Tamping irons are used around man-hole covers, near curbs, etc., where the roller can not conveniently be used. Fig. 155 shows two forms of asphalt tampers. The left-hand one is 8 inches in diameter and weighs about 30 lb.; and the right-hand one has a face $2\frac{1}{2} \times 5$ inches and weighs about 18 lb. Hot smoothing irons, Fig. 156, page 438, are employed to finish the gutters, angles, edges, and all joints or junctures where one day's work joins that of another. The tampers

and smoothing irons are heated in a metal basket which is moved forward on wheels.

Formerly the first rolling was done with a light hand roller with

FIG. 154.—SPREADING THE WEARING COAT OF AN ASPHALT PAVEMENT.

a very long handle. Fig. 157, page 438, shows a form of hand roller formerly used. The hand roller has been abandoned in favor of a light self-propelling tandem roller (Fig. 71, page 213). The use of

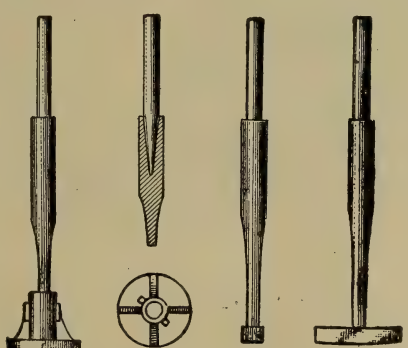

FIG. 155.—TAMPERS FOR ASPHALT PAVEMENTS.

hot smoothing irons and hot rollers are objectionable since it is impossible always to have them of such a temperature as not to injure the pavement; and since, if the mixture is delivered at the proper

temperature, and the raking and spreading is done expeditiously, they are unnecessary. Experience shows that the surface of pavements upon which hot smoothing irons were used scales and flakes off more than a surface laid without hot tools.

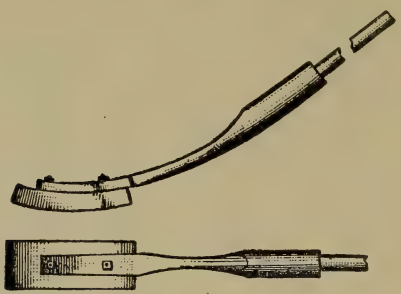

FIG. 156.—ASPHALT SMOOTHING IRONS.

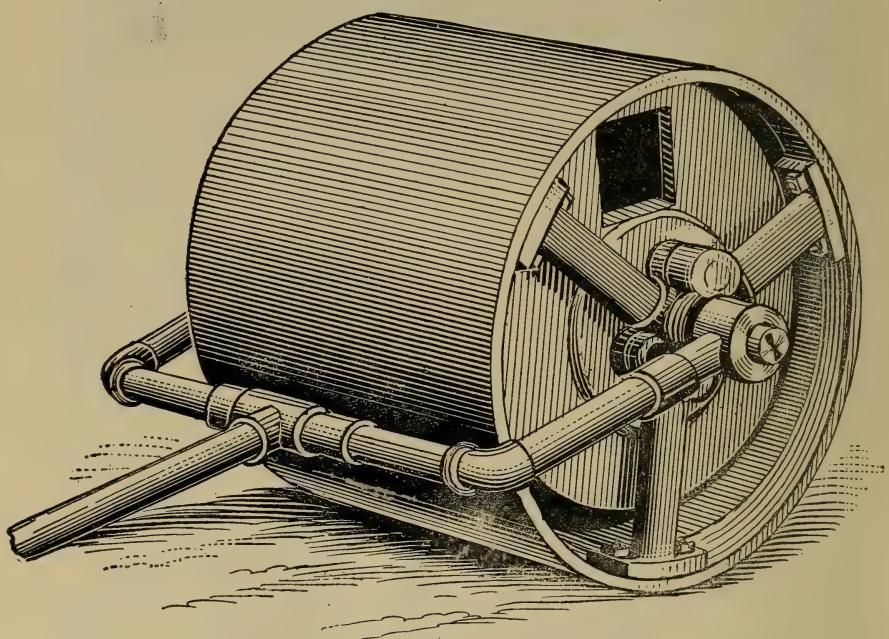

FIG. 157.—HAND ASPHALT-ROLLER WITH FIRE POT.

841. Rolling. Immediately after being spread the wearing coat should be rolled. It is important that the rolling should closely follow the spreading, so that the material shall not cool before the final compression is obtained. The state of the weather is an element to be considered; for if a strong wind be blowing, the material,

spread over a broad surface only 2 or 3 inches thick, will cool much more rapidly than on a calm day when the temperature is considerably lower.

It is usually specified that the rolling shall be finished with a roller giving a compression of at least 200 lb. per lineal inch. But to secure the best results the rolling should be begun with a $2\frac{1}{2}$-ton tandem roller, and be followed with a 5-ton roller, and be completed with an 8-ton roller. The first gives a compression of about 60 lb. per linear inch of face under the front roll and about 125 under the driving drum; the second 200, and the third 280, under the driving drum. Usually only a 5-ton and an 8-ton roller are used, and sometimes only an 8- or 10-ton. The attempts to do all the rolling with a single 8- or 10-ton roller is very objectionable, since the roller is too heavy for the hot material, and hence the rolling is delayed until the mixture is too cold to compact well. Further, the maximum compression can not be produced by pressure alone, but requires somewhat of a kneading action; and hence several passages of a light roller are better than fewer passages of a heavier roller. On the other hand, the heavier roller is needed at the end of the rolling to secure the greatest possible compression. Many loaded-wagon tires give a greater pressure per inch of face than the heaviest asphalt roller; and therefore if the rolling is not done with a reasonably heavy roller and is not long continued, the traffic may make indentations on the surface and possibly seriously push the wearing coat out of place.

The lubricating effect of the warm asphalt aids in the compression, so that under the roller the grains of sand are wedged together and the finer particles worked into the voids, until the mixture occupies less space than the mineral aggregate alone could possibly be made to occupy. This is proved by the fact that if all the bitumen be extracted from a fragment of good pavement of known volume, it is found to be quite impossible to reduce the dry sand obtained to as small a volume as it occupied in the pavement.

If the asphalt mixture adheres to the roller, the face of the roller may be slightly moistened with a mixture of kerosene and water. Sometimes water is sprayed on the roller; but the use of an excessive amount of water should not be allowed. The sticking can be prevented by sprinkling or dusting portland cement on the pavement.

If the street is wide enough, the pavement should be rolled transversely as well as longitudinally; and if this is not possible, the roller should run as obliquely as possible, so that any little inequality

which might be caused by the roller's moving lengthwise may be taken out by the cross action. The rolling should be kept up until the heaviest roller leaves no mark, a result which usually requires at least 5 hours for each one thousand square yards of surface.

New York City specifies that the rolling shall be continued until the wearing coat has a stated specific gravity, viz., 2.10 for a pavement laid between April 1st and December 1st, and not less than 2.05 for a pavement laid between December 1 and April 1. For data on laboratory tests of density, see § 832.

As soon as the rolling is completed, the pavement may be thrown open. Traffic, if not of too heavy vehicles, is an advantage to a newly laid asphalt pavement, since the pressure of the wheels aids in consolidating the wearing coat and in closing the surface, a result which helps to retain the volatile oils and prevents the entrance of water. Asphalt pavements in unfrequented streets do not wear so well as those under a moderately heavy traffic.

Fig. 158 shows two rollers rolling the wearing surface of an asphalt pavement on Fifth Avenue, New York City.

FIG. 158.—ROLLING THE WEARING COAT OF AN ASPHALT PAVEMENT.

842. In spreading and raking the wearing coat there is a tendency for the workmen to step on the uncompressed mixture. If the foot-print is filled by raking material into it, this part will con-

tain more material, and hence when rolled it will not be brought down even with the adjoining portion and a hump in the finished pavement will result. The bump of passing wheels against this hump and the impact due to the drop of the wheel after having passed the hump are nearly certain to cause a gradually increasing movement of the wearing coat. Therefore stepping on the uncompressed wearing coat should be absolutely prohibited; and if it does take place, the foot-print should be thoroughly obliterated by raking or at least the track should not be filled with loose material.

For much the same reasons as in the preceding paragraph, all compressed lumps of the wearing coat should be broken up with the rake. Lumps in the uncompressed material make humps in the finished surface; and the rebound of wheels in passing such humps causes displacements of the wearing coat and starts waves.

843. Thickness of Wearing Coat. The wearing coat is usually $1\frac{1}{2}$ or 2 inches thick, the former for light traffic and the latter for heavy. It has been established that if the wearing coat is more than 2 inches thick, there is danger of its flowing under travel, i. e., working into humps and waves.

For data on the thickness employed in various cities, see Table 46, page 453.

844. The area that should be covered by a given weight of material can be determined in either of the two methods described for laying the binder course—see § 824. The method of determining the area by computation is more appropriate for the wearing coat than for the binder course, since often the specific gravity of the former is determined in fixing proper proportions of the ingredients, and also since the specific gravity of the wearing coat is not likely to vary as much as that of the binder course.

If the thickness of the wearing coat is determined by probing, the test should be made with a putty knife rather than an awl, as in probing the binder course, so that the knife edge will be arrested by the stones of the binder course.

845. Some engineers specify that when completed the top of the wearing coat shall be $\frac{1}{4}$ inch above the top surface of the gutter flag, to allow for further compression by traffic without bringing the surface of the asphalt below the top of the gutter flag. This is of doubtful wisdom, since it constructs a shoulder to eliminate the possibility of one being formed by travel.

846. ASPHALT ADJACENT TO TRACK. It is difficult to lay and maintain sheet asphalt next to the rails of a street-car track. It is

well known that many more failures of pavements occur on streets having car tracks than on those without tracks, and that most of these failures are adjacent and parallel to the rails. Part of the difficulties is due to the foundation, the ties, and the rails; and these have already been considered in Art. 3 of Chapter XV—Foundations of Street-Railway Tracks. Part of the difficulties with sheet asphalt is in getting a good union between the asphalt and the rail. The hot asphalt should be compressed thoroughly under and around the head and flange of the rail; and a good union can not be obtained if the rail is cold, since the asphalt will become chilled, and then can not be compressed and will not adhere to the rail. The surface of the asphalt should be laid even with the top of the rail. If it is laid lower, the rail will be an obstruction to vehicular travel, and vehicle wheels will follow the rail and make a rut next to the rail; and if the surface of the asphalt is laid higher than the top of the rail, steel-tired wheels will break down the edge of the pavement.

Fig. 159 shows the method of laying sheet asphalt adjacent to railroad rails adopted in Hartford, Conn.*

Notice in Fig. 159 that the asphalt is in contact with the rail. It is troublesome to maintain the connection between the rail and the asphalt because the deflection of the rail will break the bond

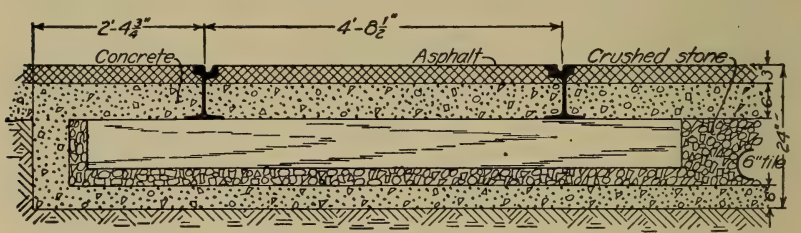

Fig. 159.—Standard Practice in Hartford, Conn.

and permit water to penetrate to the open binder where it freezes and lifts the wearing coat, and this allows the process to be repeated upon a larger scale. The only preventive is to apply a thick coat of soft or rather elastic asphaltic cement to the sides of the rail before laying either the binder course or the wearing coat; and after the pavement is in service, the only remedy is to fill the crack adjacent to the rail frequently during freezing weather.

Notice that Fig. 159 is for a grooved rail; but the same form of construction would apply equally well with a T rail.

* *Engineering News*, Vol. 73 (1915), p. 888.

The Baltimore (Md.) Pavement Commission has recently adopted the method of laying sheet asphalt pavements adjacent to street-railway tracks shown in Fig. 160.* Notice that a vitrified paving block intervenes between the asphalt and the rail. The advantage of this construction is that the vitrified blocks can be put into place before the laying of the asphalt is begun. The extreme form of the construction shown in Fig. 160 is that in which the whole area between the ends of the ties is paved with vitrified blocks—see Fig. 196, page 540, which also is a standard in Baltimore.

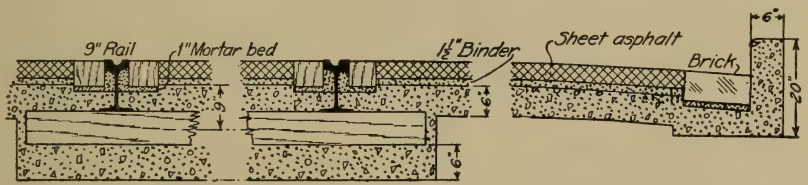

FIG. 160.—STANDARD PRACTICE IN BALTIMORE, MD.

847. CAUSES OF FAILURE. The construction of an asphalt pavement involves greater care in selecting and combining the ingredients than most other kinds of pavements. Most other forms of pavements are constructed of a natural or artificial surfacing material which is prepared and inspected (at least in part) before being brought on to the street and which needs only to be laid, while the important parts of a sheet asphalt pavement must be fabricated in place on the street; and hence greater care is required in the laying.

Unfortunately the custom has been to contract with asphalt paving companies to lay asphalt pavements and to guarantee them for a term of years, and consequently the municipalities have as a rule made little or no investigation of the materials used nor of the methods employed in laying the pavement. The result is that there are but few, if any, public records showing the history of the pavement; and therefore it is often impossible to determine the cause of either failure or success. The causes of failure, exclusive of those due to faulty foundation and street-railway track, may be grouped under the following heads. Unsuitable material, improper manipulation, and deterioration in use.

848. Unsuitable Material. The sand should be clean, hard, and properly graded; the filler should be hard and properly graded;

* *Engineering News*, Vol. 73 (1915), p. 884.

the asphalt cement should meet the usual specifications, particularly as to consistency or penetration. Each of these items has already been discussed; and the best means of preventing failure under this head is to observe the standard specifications.

849. Improper Manipulation. Even though the materials may be the best, there is an abundant opportunity for failure through improper manipulation in heating and mixing the materials.

850. *Burned Asphalt.* The asphalt may have been damaged by over-heating or "burning." The burning of the asphalt causes the surface of the pavement to disintegrate in spots during cold weather; and may be revealed by a brittleness and a tendency to crack while being rolled. Excessive heat converts the petroline, or cementitious constituent of asphalt, into asphaltine, which is devoid of cementing properties, and by so much reduces the cementing quality —the vital element—of the asphalt. This over-heating may take place during the refining (§ 492), or during the fluxing (§ 530), or in mixing the asphaltic cement and the sand (§ 838).

Sometimes the kettle is mounted within brick walls directly over a fire which comes in contact with only a comparatively small part of the heating surface, in which case it is highly improbable that the firing will be done so evenly and slowly as not to burn at least part of the asphalt. The fire should not be allowed to come in direct contact with the melting kettle or tank, thereby guaranteeing that no portion of the asphalt can be burned. When the asphalt has been badly burned, it will be revealed by a brittleness during rolling; but there is no way of determining a lesser degree of burning, although it still may be sufficient to cause a serious defect which will finally develop into cracks and rotten spots. Therefore the inspector should insist upon a method of melting that will insure an unburned product. It is usually specified that the asphalt shall be heated by steam.

The over-heating of the asphalt may be produced also by over-heating the sand (§ 838). Every precaution should be used to have each batch of sand heated uniformly throughout, and its temperature should be taken before mixing it with the asphalt. As a further check, the temperature of each load of paving compound sent to the street should be taken and recorded at the mixing plant.

851. *Improper Consistency.* The paving cement may have been mixed too hard or too soft. If the cement is too hard, the pavement will have a tendency to crack during cold weather; and if it

is too soft, it will push out of place and form rolls or waves under traffic.

852. *Insufficient Bitumen.* The wearing coat may not have contained sufficient cementing material (§ 830). Within the limits imposed by the proper softness and hardness of the pavement, the greater the per cent of asphalt the greater the life of the pavement; and consequently contractors in laying a pavement under a long-time guarantee generally use the maximum amount of asphaltic cement, but when the maintenance period is short they generally use the minimum. In fluxing, the tendency is for the bitumen to rise and the mineral impurities to settle; and consequently if the tank is worked too low, there is a likelihood that the last material taken from the tank will contain too small a proportion of bitumen and too large a proportion of sediment or mineral matter. This can be prevented by careful inspection and by frequently taking samples and analyzing them.

853. *Inadequate Mixing.* The ingredients of the wearing coat may not have been sufficiently mixed. It is important that each grain of sand shall be entirely surrounded by the cementing material, so that no two pieces shall come into actual contact. If the mixing is not well done, the pavement will disintegrate in spots.

854. *Rich Binder.* If an excess of asphalt is used in the binder course, it is likely to work to the surface of that course and then being absorbed by the wearing coat cause it to disintegrate. This cause of failure manifests itself by irregular blotches on the surface of the pavement.

855. *Cement Chilled.* The mixture for the wearing coat may become chilled while being transported from the mixing plant to the street. To prevent this possibility, the temperature of each load should be taken just before it is laid. The material may also become chilled by a delay in tamping and rolling, or by attempting to work during too cold weather or during the prevalence of a high wind. A batch of chilled mixture will cause a weak spot in the pavement.

856. *Separation of Cement and Sand.* If the distance from the plant to the street is long or there is unusual delay, some of the asphaltic cement may work down to the bottom of the load, and when the material is dumped there will be both rich and lean spots —both of which are equally objectionable. The rich spots will have a tendency to roll or crowd toward the gutter; and the lean spots will have a tendency to disintegrate under traffic.

857. *Damp or Dirty Foundation.* The wearing coat may have

been laid on a dirty or damp foundation, and therefore have been prevented from uniting firmly with the foundation. This condition will be revealed by a tendency of the pavement to roll or push out of place while sound and firm on the surface.

858. *Inadequate Compression.* The wearing coat may not have received sufficient compression. The surface must be thoroughly compacted—particularly in the gutters—to keep out rain water and the acids and oxygen dissolved in it. The effect of oxidation is gradually to destroy the cementing power of the bitumen.

859. Deterioration in Service. All materials in nature are undergoing changes due to the action of the elements, and asphalt pavements are no exception. The following are some of the principal causes leading to the gradual deterioration of such pavements.

860. *Ordinary Wear.* The pavement may decrease in thickness due to loss of material by the abrasion of hoofs and wheels; but since the surface is smooth and somewhat elastic, the loss by wear is almost imperceptible. In some cases the pavement decreases in thickness with use, but the decrease is due to consolidation rather than to loss of material.

861. *Natural Decay.* All asphalts gradually lose their cementing power with age by volatilization, evaporation, and oxidation. The pavement is peculiarly exposed to the action of the sun's heat, and to the combined action of rain water, acids, oxygen, and frost. The greater the cementing power of the asphalt originally and the softer the cement, the longer the pavement will resist the influence of volatilization and evaporation; and the more nearly the voids of the sand are filled with cement and the more firmly the pavement is consolidated, the longer it will resist the action of water, acids, oxygen, and frost. The general decay of the asphalt will be indicated by a tendency of cracks to form during cold weather (§ 866), particularly during a sudden and extreme drop in the temperature.

862. *Weak Foundation.* A weak or improperly prepared foundation by unequal settlement or settlement in spots will cause cracks and depressions in the surface which under traffic will speedily enlarge and cause the pavement soon to break up.

863. *Porous Foundation.* A porous foundation permits the ground water to rise, by capillary action and possibly also by hydrostatic pressure, to the underside of the wearing coat, where by freezing it may break the bond between the top layer and the base, and thus permit the wearing coat to be pushed out of place and broken. This effect has been known to occur with a concrete foun-

dation; but it is not likely to occur with good concrete. If a section of pavement disintegrating from this cause be examined, there will be found a layer of perfectly sound and good material at the surface, while the lower side of the wearing coat will show evidence of being disintegrated by water—that is, the sand will appear clean and white in spots as though there had been insufficient asphalt cement to cover it. The concrete base under the affected spot will generally be found to be damp or even wet. This defect may be prevented by underdraining the soil.

864. *Leaky Joints.* Lack of a water-tight joint between the asphalt surface and the curb, the gutter, man-hole covers, crossings, street-car rails, etc., may permit the water to enter the lower and less compact part of the wearing coat, where by its solvent action and also by freezing it may do material damage. It is nearly impossible to keep these joints tight, particularly adjacent to the street-car rails. The damage often extends a considerable distance from the place where the water enters.

865. *Illuminating Gas.* Ordinary illuminating gas, escaping from leaky pipes under the pavement, is absorbed by the pavement, and causes the disintegration of the asphalt. There is but one way to stop the disintegration of a pavement from this cause, and that is to stop the leak of gas.

Pavements affected by illuminating gas first give signs of their disintegration by a slight depression over the affected spot, later fine cracks appear parallel to the line of the street, and finally the surface coat begins to crown.

866. *Cracks.* Long irregular cracks in the wearing surface frequently occur during cold weather. They usually start at the gutter or man-hole frame, and gradually extend across the street. They are often found at the joint between an old and a new pavement or at the joint made between one day's work and another. These cracks are due to the contraction of the wearing surface, and should not be confounded with cracks due to the failure of the foundation. Usually these cracks do not occur until the pavement is two or three years old; at least they are most likely to occur in an old pavement—one in which the asphalt has lost part of its cementing power by age. These cracks appear sooner and increase more rapidly on a street having only a light traffic. When the pavement is subjected to a continuous traffic, the asphalt surface which is more or less plastic at all temperatures, is kept from cracking by the constant kneading action of the traffic. Again, when an

asphalt surface has but little or no traffic, it becomes more porous owing to expansion and contraction from heat and cold without the compression due to traffic, and as a consequence is materially weakened. If cracks occur on a street having a fair amount of traffic, it is evident that the paving mixture is at fault—either there was not enough bitumen or the asphalt cement was too hard.

Some engineers leave expansion joints, i. e., cut the wearing coat through, at intervals to prevent these irregular contraction cracks. Such a procedure is of doubtful propriety, since the pavement if properly constructed will not crack in several years under the most adverse conditions, and then only at long intervals and generally at some old joint; and if the pavement is improperly made, the expansion joint will have only a slight tendency to prevent these irregular cracks. The principle of the expansion joint is not applicable to materials with no structural strength, like asphalt mixtures. These joints are not only useless, but really detrimental to a pavement. They are only another form of the defect they are intended to remedy, for they are crevices which retain mud and water which tend to rot the asphalt, and the edges of the joints are easily broken down by traffic which also widens the crack.

867. *Shifting under Traffic.* The surface coat sometimes flows under traffic, i. e., pushes lengthwise of the street into waves or crowds toward the gutter. This defect occurs in pavements having too soft a wearing surface, or where there is a defective bond either between the base and the binder, or between the binder and the wearing surface. This is a defect that is impossible to guard against entirely on a street having very heavy traffic, and especially where the traffic is confined to a narrow section of the street; but this defect is inexcusable on streets having only moderately heavy traffic. This flowing is commonly caused by the surface of the hydraulic concrete base under the pavement being too smooth, which is the case where gravel concrete is used or where a stone-and-gravel concrete is so rich that its surface is covered with mortar that was brought to the top by ramming. Unless the binder and the surface mixtures are made very hard, a condition which makes the pavement likely to crack, the wearing coat will slide on such a base if there is much traffic. Pavements often roll from a defect in the binder—either because it was too rich in asphaltic cement, or because it was dirty when the wearing surface was laid.

868. *Damage by Bonfires.* Another cause of damage to asphalt pavements is the building of fires upon them. Of course this ought

never to occur, but even in the best regulated municipalities it does sometimes happen.

869. METHODS OF REPAIRING. The repairs necessitated in the maintenance of an asphalt pavement may be classified as follows: (1) those due to a settlement of the subgrade; (2) those due to a disintegration of the pavement in spots; (3) those due to the formation of waves; (4) those due to the formation of cracks; (5) the painting of the gutter; and (6) the remedying of defects next to the street-car rails, crossing stones, man-hole covers, etc.

870. Settlement of Subgrade. The majority of repairs are necessitated by the settlement of the foundation over trenches. To repair these defects, it is necessary to remove the wearing coat, the binder, and the foundation; and then, after having consolidated the material in the trench (see § 764), to re-lay the pavement much as in the original construction. The edges of the binder course and also of the wearing coat should be thoroughly covered with a thin coat of asphaltic cement to secure a perfect union of the old and the new material. Both the binder course and the wearing coat should be thoroughly tamped or rolled. Owing to the difficulty of fully consolidating the patch, it is left a trifle high to prevent a possible depression.

871. Disintegration. If the wearing coat disintegrates in spots, or forms " macaroons," from any of the causes described in § 848–65, the affected part must generally be cut out, since it is usually affected to its full depth. If the binder course is the cause of the deterioration (see § 812), it also must be cut out. The new material is to be laid as described in the preceding paragraph. If the disintegration does not extend to the full depth of the wearing coat, the repair may be made by " skimming," as described in the succeeding paragraph.

872. Formation of Waves or Humps. If the wearing coat has shifted under the traffic so as to form waves, i. e., until it is thicker in some parts than others, or if the wearing coat has crowded towards the gutter, it may be necessary to melt off a portion of the high part, and also to re-surface the thin part. This is called skimming. The asphalt is melted off either with an open grate on low wheels in which coke is burned; or with a special heater having a tank for gasoline, a hood over the burner, and an asbestos mat to protect the adjacent pavement. Fig. 161 shows one of several forms of surface heaters in common use. The surface is heated until the affected portion can be raked off; and then new material is added to bring the pavement to its proper thickness.

" Whenever the surface-heater or skimming method is employed,

all defective surface shall be removed before replacing it with new material. In all cases the old surface shall be removed to a depth of not less than one quarter inch; and the new surface must, when compressed, be not less than one half inch in thickness. The heat shall be applied in such a manner as not to injure the remaining

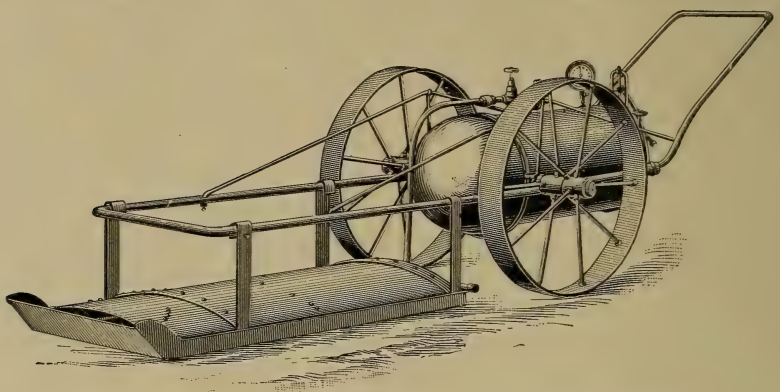

FIG. 161.—SURFACE HEATER FOR REPAIRING ASPHALT PAVEMENTS.

pavement. All burnt and loose material shall at once be completely removed; and, while the remaining portion of the old pavement is still warm, the new material shall be placed. The new and freshly prepared wearing coat shall be laid in strict accordance with the specifications for the original pavement." *

873. Cracks. When cracks have formed in the wearing coat, all the loose material is cut off, the crack is cleaned out, and hot asphaltic cement is poured in.

874. Painting Gutters. Owing to the disintegrating effect of water, asphalt gutters usually require comparatively frequent repairs either by painting with asphalt rich in bitumen, or by skimming (§ 872), or by removing the wearing coat and re-laying it, using an asphalt richer in bitumen than that in the remainder of the pavement.

875. Recording Repairs. The present practice is to make the repairs to asphalt pavements by contract with a guarantee of the work for a number of years; therefore it is important that a record should be kept of the area and location of the several patches and also of the date when each was made. This is done by dividing the pavement into imaginary squares, say, 10 feet on a side; and

* Specifications of Amer. Soc. of Municipal Improvements for Sheet Asphalt Paving, approved Oct. 14, 1915, p. 12.

then when a patch is to be made, one or more of these squares should be located by chalk marks on the pavement, and the boundary of the patch should be sketched in a cross-ruled note-book. The records of the individual patches are afterwards platted upon a single sheet to see that a subsequent patch does not overlap one for which the guarantee has not expired.

876. Using Old Materials. In some cities it is customary to permit the re-use of the old asphalt; but this is of doubtful widsom, since usually the repair is required by the inferiority of the old material, and since it is likely to be over-heated in being removed. If the asphalt is not damaged, and is cut out with an axe, it may be used again, provided (1) the pieces are kept clean, (2) it is re-heated slowly and carefully, and (3) new asphalt is added to flux the old. It is difficult to melt old material without burning it, and it is also difficult to secure a uniform mixture with it.

877. Cost of Construction of Sheet Asphalt Pavements. Asphalt pavements are comparatively expensive, since the tools and machinery employed in mixing and laying the asphalt are costly and subject to large depreciation whether idle or in use, and also since the business requires a considerable proportion of skilled labor. One of the peculiarities of the business is the disproportionate amount of capital invested in the plant compared with the business done, often an expensive plant being maintained in a city for one or more years without laying any pavement or at most only a small amount. Or a portable plant is moved to a small city for a comparatively small amount of pavement. Another peculiarity is that the working season is short, extending only from, say, the first of May to the first of November; and as expert superintendents and foremen are indispensable, it is necessary to employ this skilled labor by the year.

878. In connection with data on the cost of construction of a pavement, it should not be overlooked that the cost of the pavement proper is not usually the total cost which the property holder must pay for the improvement of the street when it is paved. Usually the improvement of the street includes four items, viz.: (1) excavation for the pavement, (2) the construction of curbs and gutters, (3) laying drains and building catch basins, man-holes, etc., and (4) the pavement itself. 1. Under ordinary conditions the excavation, exclusive of surfacing and rolling the subgrade, will cost 10 to 15 cents per square yard. 2. Combined concrete curbs and gutters (§ 737), will usually cost 30 to 35 cents per square yard of pavement

3. The drainage will usually cost 10 to 15 cents per square yard of pavement. These three items may add 50 to 60 cents per square yard to the cost of the pavement proper.

879. Estimated Cost. The estimate of the cost of laying an asphalt pavement shown in Table 45 was prepared for this volume by a man of acknowledged ability and unquestioned integrity, who has had 20 to 25 years' experience as an inspecting and consulting engineer of asphalt paving in various cities.* The estimate is for a city in which 100,000 square yards are laid in one year.

The table is chiefly interesting as showing the items that go to make up the expenses which are separate and distinct from that for materials and labor. Of course, these expenses would be less or more per square yard, if the area of pavements laid was greater or less than the amount stated. The estimate is for first-class work under average conditions prevailing in 1916.

880. Actual Cost. Table 46, page 454, shows the contract price for constructing sheet asphalt pavements in thirty-three cities.

881. Cost of Maintenance. The cost of maintenance will vary with the original quality of the pavement, its age, the amount and nature of the traffic, the width of the street, the presence or absence of street-car tracks, the frequency with which the pavement is cleaned and sprinkled, the climate, etc.

In nearly all American cities there is a serious lack of data concerning the cost of maintaining pavements; and this lack is more serious for sheet asphalt pavements than other forms, since this type involves more variables. A few cities attempt to keep a record of the cost of maintaining pavements; but such records are often so incomplete and so incorrectly compiled as to be valueless. Some of the reasons for the dearth and incompleteness of the data on the cost of maintaining sheet asphalt pavements are as follows:

1. The pavement is usually built under a long-time guarantee, and the city pays comparatively little attention to the quality of the materials used and the methods of construction employed; consequently there is no satisfactory record of the quality of the pavement. In some cases the date when the pavement was laid or re-surfaced is unknown; and in many cities no adequate records are kept of the location of repairs or patches. In recent years cities are improving in this respect; but the usual absence of such records

*A. W. Dow, for a number of years Inspector of Asphalt and Asphalt Paving for the District of Columbia, and for several years past a consulting asphalt chemist and asphalt paving engineer in New York City.

TABLE 45

ESTIMATED COST OF SHEET ASPHALT PAVEMENT

Plant and Capital Charges:		
Interest on cost of fixed plant,—5% on $13,500	$675.00	
Interest on cost of rollers, tools, etc.,—5% of $3,000	150.00	
Taxes,—1% of $10,000	100.00	
Insurance,—4% of $10,000	400.00	
Depreciation,—8% of $16,500	1,320.00	
Rental or interest on real estate,—5% of $4,000	200.00	
Interest for 6 months on working capital,—5% of $6,000	150.00	
Current repairs	500.00	
Watchman for 1 year	400.00	
Total for 100,000 square yards	$3,895.00	
Total for 1 square yard		.039
Local Management and Clerical Expenses:		
Rent of office 1 year	$400.00	
Telephone, light, water, etc.	100.00	
Salary of superintendent,—1 year	2,000.00	
Cashier in charge of office,—1 year	1,200.00	
Clerks, timekeepers, etc.,—6 months	700.00	
Proportionate part of winter pay roll	750.00	
Total for 100,000 square yards	$5,150.00	
Total for 1 square yard		.051
General Officers and Offices:		
Laboratory and general expenses		.030
Expense Securing Contracts:		
Agent's commission, legal and traveling expenses, etc		.050
Material and Labor per Square Yard:		
Subgrade,—0.25 cubic yard, grading, rolling, etc	0.125	
Foundation,—6 inches of concrete (1 P. C.: 3 S.; 6 B. S.)	.700	
Binder—1 inch complete	.170	
Wearing surface—2 inches:		
22 lb. of asphalt cement at $20 per ton	.220	
0.083 cubic yard sand at $1.20	.100	
16 lb. pulverized limestone at $3.50 per ton	.030	
Fuel used at plant	.020	
Oil, waste and sundries	.002	
Labor at plant	.060	
Hauling material to street	.030	
Laying and rolling	.050	
Total for materials and labor		$1.507
Cost of Guaranty:		
5 years at 2½ cents per year		1.00
Total cost of pavement, per square yard		$1.777

TABLE 46

COST OF CONSTRUCTION OF SHEET ASPHALT PAVEMENTS *

Laid in 1916

Ref. No.	Locality. State.	Locality. City.	Amount Laid Sq. Yd.	Concrete Base. Thickness.	Concrete Base. Proportions.	Binder Course. Thickness.	Binder Course. Per Cent Bitumen.	Wearing Coat. Thickness.	Wearing Coat. Per Cent Bitumen.	Cost of Base, Binder and Wearing Coat, per Sq. Yd.
1	California	Long Beach	11 972	4″	1 : 3 : 6	1″	....	1½″	.....	$1.56
2	"	San Diego	12 043	5″	1 : 3 : 5	1″	....	2″	.....	1.50
3	"	Santa Monica	34 910	5″	1 : 3 : 6	1″	....	2″	.....	1.22
4	Connecticut	Hartford	32 195	6″	1 : 2 : 3	1½	....	1½	.....	1.58
5	"	New Haven	92 742	6″	1 : 3 : 6	1½	5–8	1½	10–12	1.84
6	Dist. of Col.	Washington	154 076	6	1 : 3 : 7	1½	....	2½	.....	1.66
7	Illinois	Chicago	1 248 000	6	1 : 3 : 6	1½	....	2	.....	1.89
8	"	Moline	36 059	5	1 : 3 : 6	1½	....	2	.....	1.81
9	Indiana	Ft. Wayne	45 112	6	1 : 3 : 6	1	....	1½	.....	1.70
10	"	Goshen	24 046	6	1 : 3 : 5	1	....	1½	.....	1.56
11	"	South Bend	18 702	6	1 : 7G	1½	4–6	2	11	1.81
12	"	Vincennes	107 506	5	1 : 5	1	5.5	1½	10.5	1.66
13	Iowa	Mason City	131 489	5	1 : 3 : 6	1	6	1½	11	1.68
14	"	Sioux City	11 000	5	1 : 2½ : 4	1½	....	2	.....	2.10
15	Kansas	Newton	113 200	4	1 : 2 : 4	0	....	2	.....	1.26
16	Kentucky	Louisville	47 747	6	1 : 3 : 6	1–1½	....	2	.....	1.74
17	Maryland	Baltimore	9 257	4–6	1 : 3 : 6	1½	....	1½	.....	1.37
18	Michigan	Detroit	12 408	6	1 : 3 : 6	1½	....	2	.....	2.04
19	Minnesota	Duluth	21 300	6	1 : 3 : 6	1	6	2	.....	2.14
20	Nebraska	Omaha	23 150	5	1 : 3 : 6	1½	....	1½–2	.....	1.90
21	New Jersey	Elizabeth	25 000	6	1 : 3 : 6	1½	....	1½	.....	1.60
22	New York	Syracuse	7 407	6	1 : 3 : 6	1	....	2	.....	1.68
23	North Carolina	Durham	8 000	4	1 : 3 : 6	1½	....	1½	.....	1.73
24	Ohio	Cincinnati	2 351	6	1 : 3 : 6	1½	8	1½	11	2.25
25	"	Lakewood	13 790	6	1 : 3 : 6	1	....	1½	.....	1.99
26	"	Toledo	43 357	6	1 : 3½ : 6	1½	....	1½	.....	1.99
27	"	Xenia	25 000	6	1 : 3 : 6	1	....	1½	.....	1.98
28	Pennsylvania	Pittsburg	74 134	6	1 : 3 : 6	1½	5–8	1½	10–13	2.15
29	Texas	Beaumont	66 727	5	1 : 2½ : 5	.....	....	2	.....	1.90
30	Utah	Ogden	10 585	5	1 : 3 : 6	1½	....	1½	.....	1.80
31	Washington	Seattle	146 173	5	1 : 3 : 6	1	....	2	.....	1.40
32	West Virginia	Charleston	6 450	5	1 : 2½ : 6	1	5–8	1½	9–13	1.86
33	Wisconsin	Racine	20 851	5	1 : 3 : 5	1	....	2	.....	1.99

in the past makes it impossible to make comparisons extending over any considerable length of time.

2. There are almost no data as to the amount, nature and distribution of the travel on city pavements (§ 34); and without such data it is impossible to determine the service obtained from a pavement or to make any accurate comparisons as to the cost of its maintenance.

3. Many of the records that have been kept fail to discriminate between pavements on streets with and without street-car tracks; and even if they do state the presence of a street-car track, they often fail to state the method of computing the area maintained.

4. Some cities include in the cost of maintenance the expense of

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repairing cuts made by plumbers, gas-fitters, electricians, etc., which has nothing to do with the cost of maintenance proper, i. e., with the durability or wear of the pavement.

5. In some cities the repairs are made by contract, and in some by the city's force. In some of the former cases, the amount of repairs is so small and other conditions are such as to eliminate competitive bidding; and hence the cost is abnormally high and consequently valueless. Sometimes when the repairs are made by the city's force, the record does not include all the elements of the cost. For example, the following items of cost are often omitted: (*a*) Interest on the cost of the plant and equipment employed in making the repairs; (*b*) interest on working capital; (*c*) a charge for depreciation of plant and equipment; (*d*) a charge for supervision and office expense; and (*e*) material and labor supplied by other municipal departments.

6. Almost no records of the cost of maintenance state anything as to the condition of the pavement at the beginning or the end of the period considered. It is probably impossible accurately to make such an inventory; but the bearing of such an inventory upon the results should at least be considered. The failure to consider this phase of the subject is the same as though a merchant should attempt to compute his annual profits without an inventory at the beginning and the end of his fiscal year. See §1232.

882. Obviously it is practically impossible in any city to segregate the cost of maintenance according to the quality and the age of the pavement, the amount of travel, and the presence or absence of car tracks; but a considerable improvement upon the present practice of most cities is entirely feasible and very desirable.

Owing to the dearth of accurate and definite data, it will not be possible to give much reliable or valuable information on the cost of maintenance of sheet asphalt pavements. Further, since few contractors are equipped especially for making repairs, and since the public has no knowledge of the cost of the work to the contractor, the only data submitted will be those obtained with municipal repair plants.

In this connection it is not wise to consider pavements laid before about 1895, since before that time the importance of a proper gradation of the mineral aggregate was not understood, and consequently such pavements are likely to be much inferior to the best pavements laid later.

883. Municipal Repair Plant. A sheet asphalt pavement when

constructed in accordance with good practice is a reasonably satisfactory and economical form of pavement; but it usually requires repairs at an earlier period in its life than most other pavements, and the total cost of maintenance during its useful life is also somewhat greater. It is a high-grade pavement, and therefore should have more careful and skilful attention than most other pavements. For these reasons the repair of a sheet-asphalt pavement when needed is a vitally important matter. In the early history of asphalt pavements the repairs were made by the contractor whose chief business was to build new pavements; but in recent years many cities have established municipal asphalt repair plants. The main conditions leading to this change in practice were as follows:

1. Usually there was little or no competition among contractors for the contract to repair asphalt pavements. The equipment and skill required in laying sheet asphalt pavements is so great as usually to limit the number of contractors doing this kind of work; and while competition with other forms of pavements is likely to keep the first cost of asphalt pavements within reasonable limits, there are so few asphalt-paving contractors that usually there is no competition for the maintenance of such pavements. With a municipally owned repair plant the city virtually becomes a competitor of the ordinary contractor.

2. The plant and the other equipment for pavement construction is not suitable for pavement repairs. The construction plant and equipment is designed for turning out large quantities of material, while a repair plant should be designed for turning out small quantities.

3. With a municipal repair plant old material may be used in repairing pavements that have about reached the end of their economical life, and thus utilize the old material without injuring the pavement.

4. Since the repair plant is small, repairs may be made continually and when needed, instead of being allowed to accumulate as usual under the contract method until enough repairs are called for to warrant either starting up a large plant or diverting the plant from new construction to repair work.

884. The saving through the municipal repair plant has usually been quite considerable. Table 47 shows the results for Washington, D. C., and is fairly representative of the results obtained in other cities. For a more detailed comparison for the experience of Brooklyn, N. Y., showing a more marked saving, see *Engineering*

and Contracting, Vol. 38 (1912), page 68; and for somewhat similar data for Niagara Falls, N. Y., see *Engineering Record*, Vol. 69 (1914), page 256.

TABLE 47

COST OF REPAIRS OF SHEET ASPHALT PAVEMENTS IN WASHINGTON, D. C.*
Including coal-tar surface, and excluding all pavements under guaranty.

Repaired by Contract.		Repaired By Municipal Plant.	
Year.	Cents per Sq. Yd.	Year.	Cents per Sq. Yd.
1908	3.8	1913	2.0
1909	2.3	1914	1.9
1910	2.6	1915	1.9
1911	2.2	1916	1.8
1912	2.4		

885. Cost of Repairs. *In Brooklyn with Municipal Plant.* Table 48 shows the detailed cost of making repairs to sheet asphalt pavements in Brooklyn, N. Y., with a municipal repair plant.

TABLE 48

COST OF MAINTENANCE OF SHEET ASPHALT PAVEMENTS
In Brooklyn, N. Y., in 1911, with Municipal Repair Plant †

Items of Expense.	Cost in Place per Cubic Foot of Uncompressed Mixture.			
	Repairs.		Repaving.	
	Wearing Coat.	Binder Course.	Wearing Coat.	Binder Course.
Supervision and fixed charges	$0.025	$0.024	$0.025	$0.024
Supplies, repairs, etc.	0.067	0.057	0.059	0.057
Materials	0.178	0.097	0.178	0.097
Plant labor	0.046	0.043	0.046	0.043
Street labor	0.182	0.174	0.213	0.203
Trucking	0.060	0.057	0.080	0.076
Total	$0.558	$0.452	$0.601	$0.500

886. *In Buffalo by Contract.* Buffalo, N. Y., has long been noted for the extent of its sheet asphalt pavements, and also for the accuracy and completeness of its records concerning the cost of

* Private letter from Capt. J. J. Loving, Corps of Engineers, U. S. A., Assistant to the Engineer Commissioner of the District of Columbia.

† *Engineering and Contracting*, Vol. 38 (1912), p. 68.

repairs of pavements. The annual reports of the Bureau of Engineering contain voluminous statistics on the cost of construction and repair of all kinds of pavements. For example, the report for the fiscal year ending June 30, 1916, contains 179 pages of tabular matter showing the width, length, area, original cost, and the cost of repairs for each year after the expiration of the guaranty, of all the sheet asphalt pavements in the city. The report also gives a summary of similar data for several years back; and in addition contains several pages of data concerning the amount and age of all pavements, by whom built, the kind of materials used, etc.

The annual cost of repairs in Buffalo from 1902 to 1916 for substantially 3,000,000 sq. yd., varied from 1.30 to 8.27 cents per sq. yd., the average for the fourteen years being 5.06 cents per sq. yd.

The cost of maintaining 2,369,191 sq. yd. was 4.45 cents per sq. yd. per year; and the cost of repairs was 6.46 cents per sq. yd. per year. The average life of sheet asphalt pavements replaced between 1878 and 1906, was 20.51 years, being 21.77 years for streets without car track and 18.36 for streets having car tracks.

Table 49 gives some of the details concerning the cost of repairs of sheet asphalt pavement for the year ending June 30, 1916.

TABLE 49

DATA ON REPAIRS OF SHEET ASPHALT PAVEMENTS

Buffalo, N. Y., 1915–16, by contract *

REF NO.	ITEMS.	CONTRACT PRICE.	AVERAGE QUANTITY PER SQ. YD.	COST PER SQ. YD.
	July 1 *to December* 31, 1915:			
1	Wearing coat, per cubic foot	$0.37	1.3673	$0.5059
2	Binder course (open), per cubic foot	0.17	0.7276	0.1237
3	Asphalt cement, per gallon	0.18	0.1205	0.0217
4	Labor, per square yard	0.51		0.51
5	Total			$1.1613
	January 1 *to June* 30, 1916:			
6	Wearing coat, per cubic foot	0.33	1.3843	0.4568
7	Binder course (open), per cubic foot	0.17	0.8570	0.1456
8	Asphalt cement, per gallon	0.18	0.1204	0.0217
9	Labor, per square yard	0.47		0.47
10	Total			$1.0941

* Annual Report Bureau of Engineering, 1915–16, p. 68.

Fig. 162 shows the cost of repairs of sheet asphalt pavements at different ages. The pavements laid before 1898 were

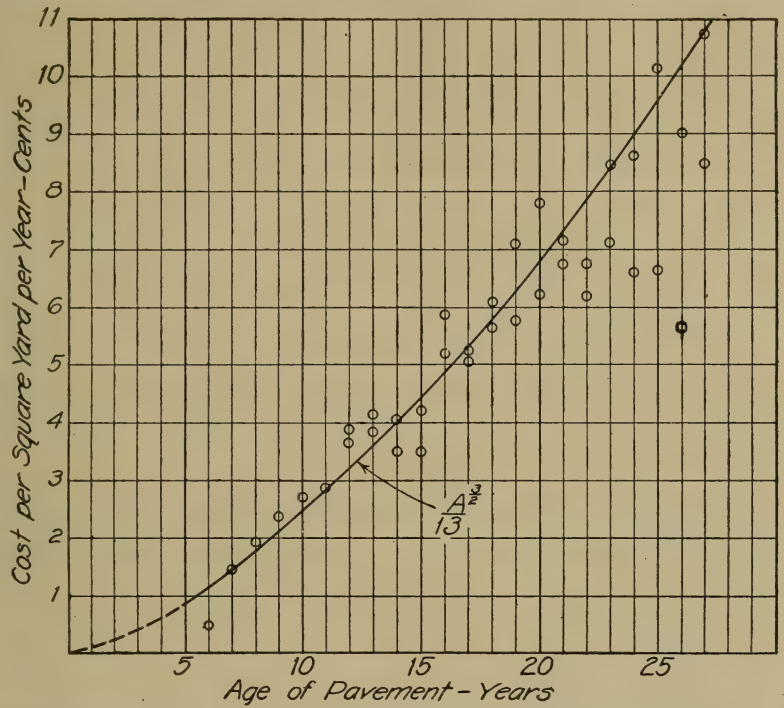


FIG. 162.—COST OF REPAIRS OF SHEET ASPHALT PAVEMENTS IN BUFFALO.

on a 5-year guaranty, and those after on a 10-year guaranty. The curve in Fig. 162 is that for $\frac{A^{\frac{3}{2}}}{13}$, in which A is the age of the pavement in years.

887. MAXIMUM GRADES FOR ASPHALT PAVEMENTS. Until within a few years, it has been assumed that the maximum permissible grade for a sheet asphalt pavement was 2 or $2\frac{1}{2}$ per cent; but experience has shown that this limit is too low. It is now generally conceded that sheet asphalt may be laid on grades of 5 or 6 per cent, particularly in residence streets—where a clean, smooth, noiseless pavement is specially desirable, and where there is usually no great amount of travel. With a 5 or 6 per cent grade, there may be a few days each year when the pavement is icy and too slippery for either comfortable or safe use. In New York City, on a street having a 6 per cent grade paved with asphalt on the sides

and granite in the center, the traffic as a rule seeks the asphalt rather than take the granite; and in the same city traffic has deserted one street having a 5 per cent grade paved with granite for another having a 6 per cent grade paved with asphalt. A number of cities have sheet asphalt pavements upon a 7 per cent grade, as, for example, Peoria, Ill., Grand Rapids, Mich., Syracuse, N. Y., Troy, N. Y.; and Omaha, Neb., and St. Joseph, Mo., have asphalt pavements on an 8 per cent grade. Scranton, Pa., has a short piece of asphalt on a 13 per cent grade; San Francisco, Cal., a piece on a 16 per cent grade; and Pittsburg, Pa., one on a 17 per cent grade.

A committee of the American Society of Civil Engineers recommends 5 per cent as the permissible maximum grade for sheet asphalt —see Table 15, page 57.

888. Crown for Sheet Asphalt Pavements. The special committee of the American Society of Civil Engineers recommends that the crown shall be between $\frac{1}{4}$ and $\frac{1}{8}$ of an inch per foot of the half width, see Table 16, page 65.

889. Merits and Defects of Sheet Asphalt Pavements. The advantages possessed by monolithic asphalt pavements constructed as described above are: (1) they produce neither dust nor mud; (2) they are comparatively noiseless, except for the clicking of the horses' shoes; (3) they do not absorb or retain noxious liquids, but facilitate their prompt discharge into the gutters and storm-water sewers; (4) they reduce the force of traction to a moderate amount (see Table 8, page 21); and (5) they afford a reasonably good foothold for horses.

The defects of sheet asphalt pavements are: 1, the first cost is comparatively great; 2, the cost of maintenance is large; and 3, such pavements are generally considered too smooth for steep grades.

For a discussion of the relative merits of the different pavements, see Chapter XX.

890. Specifications for Sheet Asphalt Pavements. The American Society for Municipal Improvements on October 14, 1915, adopted Specifications for Sheet Asphalt Paving, printed copies of which may be had of the Secretary of the Society for a nominal sum. The specifications cover only the selection, preparation, and laying of the materials for the binder course and the wearing coat. These specifications are of the so-called blanket type, that is, they contain general requirements for the asphalt and asphalt cement which are intended to include all the different kinds of asphalt.

For a statement of the objections to this form of specification, see § 532; and for alternate restricted specifications for asphalt for other kinds of pavements, see § 534–41.

ART. 2. ASPHALT-CONCRETE PAVEMENTS

891. An asphalt-concrete pavement consists of a foundation of either bituminous or hydraulic-cement concrete, and a wearing coat of asphalt concrete. There are two differences between asphalt concrete and the bituminous concrete discussed in Chapter X,—Bituminous Macadam and Bituminous Concrete Roads. 1. Asphalt concrete is made with asphaltic cement, while the bituminous concrete may be made with either asphalt or tar. 2. Bituminous concrete is made with only the care usually employed in making hydraulic cement concrete, while asphaltic concrete is usually proportioned, mixed and laid with approximately as much care as sheet asphalt pavements.

The difference between a sheet asphalt pavement and an asphalt-concrete pavement is in the maximum size of the aggregate. In the former all of the aggregate will pass a No. 8 sieve, while the latter may contain 1½-inch stone. The ordinary sheet asphalt pavement could with some propriety be called a sand asphalt pavement or an asphalt mortar pavement, to distinguish it from an asphalt concrete pavement.

892. DEFINITIONS. There are several types of asphalt-concrete pavements, the best known of which are: Bitulithic, Warrenite, Amiesite, and asphalt concrete.

893. Bitulithic Pavement. This is a patented form of pavement in which the wearing coat is composed of bitumen and mineral aggregates ranging from 3 inches down to an impalpable powder. The bituminous mixture is usually mixed in a non-portable plant. The aggregate is chiefly crushed stone; and the aggregate of the seal coat is stone chips.

Six patents (No. 727,505 to 727,512) were issued to Frederick F. Warren, Newton, Mass., between May 16, 1901, and April 14, 1902, for preparing asphalt for paving purposes and for closely related forms of asphalt-pavement construction. Of the eighty-two specifications in these patents, sixty-five relate to the proportions and method of laying the pavement. Apparently the intention is to cover such gradations of the ingredients as will secure maximum density and maximum stability. The density of a sheet asphalt

pavement made with limestone filler is 2.20 to 2.22 (§ 832); but the density of a bitulithic pavement made of the same materials may be 2.28, and if the bitulithic is made of trap the density may be 2.50 or even more. This type of pavement is designed for city streets and it has been largely used for this purpose (see page 320).

894. There has been much controversy and considerable litigation as to the scope and meaning of these patents, and it is impossible to state in a single series all the gradations included. Two gradings actually employed in laying bitulithic pavements are shown in the following table.

GRADINGS OF WEARING COAT OF BITULITHIC PAVEMENTS *

	No. 1.	No. 2.
Bitumen	7.6%	7.02%
Mineral aggregate passing 200-mesh	4.9	4.58
" " " 100-mesh	4.6	3.99
" " " 80-mesh	3.2	2.76
" " " 50-mesh	7.3	7.88
" " " 40-mesh	3.1	1.27
" " " 30-mesh	2.4	2.39
" " " 20-mesh	2.2	2.13
" " " 10-mesh	5.1	3.77
" " " ¼-inch	9.1	4.85
" " " ½-inch	19.3	12.75
" " " 1½-inch	31.2	46.61
Total	100.0%	100.00%

* Agg's Construction of Roads and Pavements, p. 308.

895. Warrenite Pavement. This type of pavement is covered by the Warren patents (§ 893); and is especially designed for rural roads. The mixing is usually done in a semi-portable plant; and the ingredients are not proportioned with as much care as for bitulithic pavements (§ 893). Sand is largely used in the body of the wearing course and wholly for the seal coat.

896. Amiesite Pavement. This is a proprietory mixture of asphalt cement, sand, and broken stone up to 1¼ inches in diameter. It is mixed at a plant, and is shipped in cars to the city where it is to be laid. During transit the mixture cements into a solid mass, and must be heated before it can be shoveled from the car. To heat it, holes are dug into the mass and steam is blown into them and permeates the whole mass and softens it. This type of pavement is laid without a concrete base. The mixture is laid cold, usually in two courses, the lower being 2½ or 3 inches thick, and the wearing coat 1 or 1½ inch.

897. Topeka Mixture. An asphalt pavement somewhat like the patented bitulithic pavement was laid in Topeka and Emporia, Kansas; and as a result of a suit for infringement of patent No. 727,505, the U. S. Circuit Court in 1910 decided that the following gradation did not infringe said patent:

Bitumen				7 to 11	per	cent
Mineral aggregate passing			200-mesh	5 to 11	"	"
"	"	"	40-mesh	18 " 30	"	"
"	"	"	10-mesh	25 " 55	"	"
"	"	"	4-mesh	8 " 22	"	"
"	"	"	2-mesh	not over 10	"	

The sieves are to be used in the order named.

Notice that the aggregate is mostly sand, and $\frac{1}{4}$-inch and $\frac{1}{2}$-inch stone. Notice also that a wide variation in the grading is possible under the above specifications; and consequently many somewhat different gradings have been designated as Topeka mixture. Since 1911 many thousands of square yards of roads and pavements have been laid under the above so-called Topeka specifications.

898. The American Society of Municipal Improvements recommends the following grading,* which the Warren Brothers Co. has agreed does not infringe its patents.†

Bitumen				7 to 9	per	cent
Mineral matter passing			200-mesh	7 " 10	"	"
"	"	"	80-mesh	10 " 20	"	"
"	"	"	40-mesh	10 " 25	"	"
"	"	"	20-mesh	10 " 25	"	"
"	"	"	8-mesh	10 " 20	"	"
"	"	"	4-mesh	15 " 20	"	"
"	"	"	2-mesh	5 " 10	"	"

899. Asphalt paving blocks (see Art. 4 of this chapter) have long been made of a mixture substantially the same as the so-called Topeka mixture.

900. Stone-filled Sheet-Asphalt Pavement. The so-called Topeka mixture is frequently described as the wearing-coat mixture for a sheet asphalt pavement to which has been added $\frac{1}{4}$-inch and $\frac{1}{2}$-inch broken stone; and is sometimes referred to as a stone-filled asphalt mixture, and also as a fine asphaltic concrete.

Mr. Clifford Richardson, a recognized authority on asphalt paving, in *Engineering Record*, Vol. 65 (1912), page 718, and again in Vol. 70 (1914), page 634, shows that for the best

* Proceedings, 1915, p. 415.
† *Ibid.*, p. 423.

results possible within the limits of the above decree, the finer part of the mixture should conform to the standard gradation for sheet asphalt (§ 827) and that as much as $\frac{1}{4}$-inch and $\frac{1}{2}$-inch broken stone should be added as the ruling of the court will permit. He states that the two gradings in Table 50 have given satisfaction. The one on Riverside Drive was laid in 1913; and the one in Rochester has been in use since about 1902. Mixtures of this type have been laid extensively in the last few years.

TABLE 50

COMPOSITION OF STONE-FILLED SHEET ASPHALT PAVEMENT

(Best Topeka Mixture)

Ingredients.	Riverside Drive, N. Y. City.		Rochester, N. Y.	
	Total Mixture.	Finer Portion.	Total Mixture.	Finer Portion.
Bitumen	8.9%	11.1%	8.9%	11.1%
Mineral matter passing 200-mesh	11.9	16.5	12.3	17.1
" " " 80-mesh	14.5	20.1	10.8	15.0
" " " 40-mesh	18.6	25.9	24.2	33.7
" " " 10-mesh	18.9	26.4	16.2	22.7
" " " 4-mesh	19.1	.....	21.5	.....
" " " 2-mesh	8.1	.....	5.4	.....
Total	100.0%	100.0%	100.0%	99.6%

901. Asphalt-concrete Pavement. An asphalt-concrete pavement, in a narrower sense than the way in which that term is used in the heading of this article, is a pavement in which the gradation of the aggregates is not as carefully made as in the four forms just mentioned. It is essentially a bituminous concrete (Art. 2, Chapter X), in which the bituminous cement is asphalt.

The standard specifications of the American Society of Municipal Improvements for asphalt concrete, provide a wearing surface of asphalt cement and broken stone, and require the following gradation of the broken stone: " All of the broken stone shall pass a $1\frac{1}{4}$-inch screen; not more than 10 per cent, nor less than 1 per cent, shall be retained upon a 1-inch screen; and not more than 10 per cent, nor less than 3 per cent, shall pass a $\frac{1}{4}$-inch screen."

902. MIXING AND LAYING ASPHALT CONCRETE. The method of mixing and laying is substantially the same whatever the gradation of the aggregate. With the most careful grading the aggregate is usually heated and then separated into three sizes, not includ-

ing the dust or filler. Each size is stored in a separate bin. The predetermined weight of each size is drawn from the bin into a box resting upon a scale platform. The proper amount of asphalt cement is determined by weight. The mineral matter and the cement are heated separately to the proper temperatures, and are then put into a mixer somewhat like that shown in Fig. 146, page 419. The limiting temperatures are substantially the same as for the wearing coat of sheet asphalt pavements (§ 838).

An asphalt concrete pavement is usually laid without any binder course, as the wearing course has sufficient stability to prevent its flow or displacement under travel.

The mixture is hauled to the street, dumped, spread and raked, much the same as for the wearing coat of a sheet asphalt pavement (§ 839–40).

The rolling of an asphalt concrete pavement is a very important matter. The weight of the roller and the temperature at which the concrete is rolled depends upon the type of the mixture. The roller should be as heavy as possible without displacing the paving material. The large aggregate gives the mixture comparatively great stability, and hence it does not squeeze out under the roller as does the sand- or sheet-asphalt mixture; and therefore it is best to begin rolling as soon as the mixture is spread. The rolling is usually done with a tandem roller weighing 8, 10, or 15 tons; or with a roller of the three-wheel type weighing 10 tons. The rolling should be continued until the roller no longer leaves a mark upon the surface. The early and heavy rolling aids in securing a firm union between the asphalt concrete and the base or foundation.

903. After the rolling is completed, a coating of hot asphalt cement is applied to the surface of the pavement at the rate of about $\frac{1}{4}$ to $\frac{1}{2}$ gallon per square yard, which is immediately covered with a layer of hot $\frac{1}{8}$- to $\frac{3}{8}$-inch stone chips at the rate of about 25 lb. per square yard. The pavement is then again rolled until the chips are firmly bedded in the cement, and until the surface is dense and waterproof. This seal coat is an essential feature of an asphalt-concrete pavement, since except the best bitulithic the body of the asphalt concrete is not waterproof.

904. Cost of Asphalt-concrete Pavements. Topeka Mixture. Table 51, page 466, is an accurate analysis of the cost to the contractor of laying 18,000 square yards of Topeka asphalt-concrete pavement in Albany, Oregon, in 1916. The pavement consisted of a $3\frac{1}{2}$-inch asphalt-concrete base, and a $1\frac{1}{2}$-inch top of Topeka

mixture. The base and top were spread and rolled separately. For similar data, giving almost the same results, for another contractor in the same city the preceding year, see *Engineering News*, Vol. 73 (1915), page 1038.

905. Various Cities. Table 52, page 467, shows the composition and cost of the several types of patented asphalt-concrete pavements in 33 cities. Table 52 was compiled from the statistics from 142 cities, and contains all the places for which the data were complete.

906. Merits and Defects of Asphalt-concrete Pavements. The merits and defects claimed for asphalt-concrete pavements are: 1. An asphalt concrete pavement, in the broader meaning of that term, is cheaper than the sheet asphalt pavement, since the use of the coarser material reduces the voids and also the surface

TABLE 51

Detailed Cost of Topeka Asphalt Pavement *

Average for one week's run

Items.	Cost per Square Yard.		
	3½-inches Base.	1½-inches Top.	5-inches. Total.
Materials:			
Gravel @ $0.86 per cubic yard	$0.062	$0.013	$0.075
Sand, fine @ $1.50 per cubic yard	0.026	0.032	0.058
coarse @ $1.80 per cubic yard	0.024	0.058	0.082
Asphalt @ $12 per ton	0.078	0.089	0.167
Fuel oil @ $1.25 per bbl	0.016	0.008	0.024
Wood @ $4 per cord	.005	0.002	0.007
Coal	.005	0.003	0.008
Total for materials	.216	.205	.421
Labor:			
Plant	0.052	0.031	0.083
Street	0.044	0.032	0.076
Teams	0.013	0.008	0.0021
Total for labor	0.109	0.071	0.180
General Expense:			
Mixing plant, interest, depreciation, repairs			0.10
Roller and small tools			0.05
Overhead			0.08
Profits			0.08
Total general expense			.31
Grand total			.96

* *Engineering News*, Vol. 76 (1916), p. 103.

to be covered with cement, and hence less bitumen is required. The difference in bitumen is from 1 to 3 per cent. 2. An asphalt-concrete pavement is cheaper than a sheet asphalt one, since the former is laid in a single course. 3. An asphalt-concrete pavement is less slippery than a sheet asphalt pavement, owing to the use of the stone fragments.

But, on the other hand, an asphalt-concrete pavement will not endure under heavy travel, particularly horse-drawn steel-tired traffic, as well as a sheet asphalt pavement, since sooner or later the larger stones will be fractured and leave two uncemented surfaces which will permit motion, wear and disintegration.

TABLE 52

COST OF PATENTED ASPHALT-CONCRETE PAVEMENTS *

Laid in 1916

Ref. No.	Locality.		Area Laid, Sq. Yd.	Concrete Base		Thickness of Wearing Coat.	Cost of base and top Sq. Yd.
	State	City.		Thickness.	Proportions.		
			BITULITHIC PAVEMENT				
1	Arizona	Douglas	28,000	5″	1 : 3 : 6	2″	$2.35
2	"	Tucson	67 219	5	1 : 3 : 6	.....	2.16
3	California	Los Angeles	104 672	4–6	1 : 3 : 6	2½	1.58
4	"	Richmond	95 682	5	1 : 2 : 4	2	2.16
5	"	Santa Monica	15 870	5	1 : 3 : 6	2	1.40
6	Iowa	Creston	47 431	4	1 : 3 : 5	2	1.89
7	"	Knoxville	13 660	5	1 : 3 : 5	2	1.98
8	"	Mt. Pleasant	27 600	5	1 : 3 : 5	2	1.89
9	Minnesota	Eveleth	20 004	6	1 : 2 : 4	2	2.50
10	"	St. Cloud	4 626	5	1 : 3 : 5	2	2.15
11	"	Virginia	1 864	6	1 : 2 : 4	2	2.44
12	"	Billings	35 893	4	1 : 3 : 6	1½	1.91
13	New Jersey	Harrison	18 512	6	1 : 3 : 6	2	2.29
14	"	Irvington	7 472	6	1 : 3 : 6	2	2.40
15	"	New Brunswick	89 319	5	1 : 3 : 6	2	2.65
16	New York	Binghamton	8 147	6	1 : 3 : 6	2	2.30
17	"	Herkimer	8 680	4	1 : 3 : 6	2	2.18
18	"	New Rochelle	17 132	6	1 : 3 : 6	2	1.50
19	North Dakota	Bismarck	25 000	5	1 : 2 : 4	2	2.38
20	"	Fargo	35 712	5	1 : 6	2	2.14
21	Ohio	Cincinnati	10 914	6	1 : 3 : 6	2	2.57
22	"	Lakewood	4 112	6	1 : 3 : 6	2	2.20
23	South Dakota	Sioux Falls	42 734	6	1 : 2½ : 5	2	2.10
24	Texas	San Antonio	11 880	5	1 : 3 : 6	2	2.30
25	Wyoming	Sheridan	4 941	5	1 : 3 : 5	2	2.12
			WARRENITE PAVEMENT				
26	California	Berkeley	23 900	6	1 : 3 : 6	2	1.40
27	Connecticut	Winsted	9 801	6	stone	2	1.35
28	Montana	Great Falls	18 830	4	1 : 3 : 5	2	1.90
29	New York	Elmira	16 644	5	1 : 2½ : 5	2	2.25
30	North Carolina	Raleigh	80 000	4	1 : 3 : 6	2	1.52
			AMIESITE PAVEMENT				
31	Connecticut	Danbury	8 000	.....	macadam	2	1.05
32	New York	New Rochelle	19 297	.....	.....	2	1.29
33	"	Salamanca	12 215	.....	stone	2½	1.65

* *Municipal Engineering*, Vol. 52 (1917), p. 248–49.

Table 53 shows the composition and cost of the non-patented asphalt-concrete pavements in 32 cities.

TABLE 53

COST OF NON-PATENTED ASPHALT PAVEMENTS *

Laid in 1916

Ref. No.	Locality. State.	Locality. City.	Amount Laid, Sq. Yd.	Concrete Base. Thickness.	Concrete Base. Proportions.	Thickness of Binder Course.	Thickness of Wearing Coat.	Cost of Base, Binder, and Wearing Coat.
			TOPEKA MIXTURE					
1	California	Berkeley	36 660	5″	1 : 3 : 6	.....	2″	$1.18
2	Iowa	Fort Dodge	40 000	5	1 : 3 : 5	.....	2	1.57
3	Kansas	Great Bend	41 800	4	1 : 2½ : 5	.....	2	1.26
4	"	Topeka	64 120	5	1 : 2½ : 5	.....	2	1.35
5	Michigan	Ludington	700	6	1 : 6	.....	2	1.05
6	Missouri	Springfield	7 073	4	1 : 3 : 7	.....	2	1.22
7	Nebraska	Norfolk	63 000	6	1 : 5G	.....	2	1.51
8	North Carolina	Raleigh	70 000	4	1 : 3 : 6	.....	2	.63
9	Texas	Taylor	130 000	4	1 : 2 : 4	.....	2	1.40
			ASPHALT CONCRETE					
10	Alabama	Gadsden	.....	5″	1 : 2 : 5	2″	2″	1.36
11	Illinois	LaGrange	23 171	6	1 : 3 : 6	.....	2	1.36
12	"	Oak Park	185 241	6	1 : 3 : 6	.....	2	1.55
13	Indiana	South Bend	37 444	5	1 : 7G	2	.....	1.45
14	Iowa	Cedar Rapids	35 000	4	1 : 3 : 5	.....	2	1.49
15	"	Webster City	16 622	5	1 : 3 : 6	.....	1½	1.65
16	Kansas	Emporia	9 875	4	1 : 2½ : 5	.....	2	1.27
17	"	Manhattan	39 930	5	1 : 5	.....	2	1.22
18	Kentucky	Louis ille	20 092	6	1 : 3 : 6	.....	2	1.68
19	Michigan	Grand Rapids	14 110	5	1 : 3½ : 7	.....	2	1.65
20	Minnesota	St. Paul	91 690	5	1 : 2½ : 5	.....	2	1.60
21	Mississippi	Greenwood	8 930	4	1 : 3 : 5	.....	2	1.48
22	Nebraska	Beatrice	36 100	5	1 : 3 : 6	.....	2	1.57
23	New Jersey	Trenton	23 334	5	1 : 3 : 6	.....	2	1.75
24	New York	Batavia	1 800	5	1 : 2½ : 5	2	seal	1.75
25	"	Niagara Falls	4 560	6	1 : 3 : 6	.....	2	2.40
26	Ohio	Toledo	12 174	6	1 : 3½ : 6	.....	2	1.85
27	Oregon	Portland	18 313	5	1 : 3 : 6	1	1½	1.30
28	South Carolina	Greenville	62 000	4	1 : 3 : 6	.....	2	1.30
29	South Dakota	Mitchell	26 512	5	1 : 5½	.....	2	1.80
30	Tennessee	Chattanooga	32 126	5	1 : 3 : 6	.....	2	1.46
31	Texas	Houston	126 917	6	1 : 3 : 6	.....	2	1.80
32	Utah	Salt Lake	12 200	4	1 : 3 : 6	.....	2	1.75
33	Washington	N. Yakima	39 593	4	1 : 4 : 6	.....	2	1.17
34	West Virginia	Charleston	96 690	5	1 : 2½ : 5	.....	2	1.78
35	Wisconsin	Fond du Lac	22 475	5	1 : 3 : 5	.....	2	1.53

* *Municipal Engineering*, Vol. 52 (1917), p. 193–95.

907. SPECIFICATIONS. The American Society of Municipal Improvements on October 14, 1915, adopted complete "Specifications for Bituminous Paving," in which the binding material was the asphalt specified therein; but in 1916 the Society amended the general specifications by eliminating the special requirements for asphalt, and stating that the asphalt, the flux, and the asphalt cement should conform to the requirements for these materials given in the Specifications for Asphalt Paving (§ 542). Printed copies of the amended

specifications for " Bituminous Asphalt Concrete Paving " (Asphalt Concrete Pavements) may be had of the Secretary of that Society for a nominal sum.

With the above Specifications are printed also specifications for the wearing coat of Bitulithic Pavements.

908. The above Society also publish Specifications for Bituminous Concrete Pavements in which the mineral aggregate is the complete product of a stone crusher and in which the binding material may be any one of the asphalts described in § 539–40 or either of the two tars described in § 574–75.

ART. 3. ROCK ASPHALT PAVEMENTS

910. A rock asphalt pavement is made by crushing asphaltic limestone or sandstone, and laying it while hot upon a concrete foundation. In Europe this is the common form; and when the term asphalt pavement is used there, this kind is intended.

Rock asphalt pavements have been laid only to a comparatively small extent in America. Rock asphalt pavements have been used in a small way in California for many years, and San Francisco, Los Angeles, and other cities have several miles of such pavements. Apparently both asphaltic limestones and sandstones are used in California; but the most of the so-called rock asphalts used for paving purposes are asphaltic limestones.

A bituminous limestone to be suitable for paving purposes should be as coarse-grained as possible, should contain between 9 and 10 per cent of bitumen soluble in carbon bisulphide, and should contain very little matter volatile below 400° F. Often one or more natural rocks are mixed to secure the proper proportion of bitumen; and sometimes a natural asphalt is added to the natural rock to increase the proportion of bitumen.

911. CONSTRUCTION. The asphaltic rock is quarried, and then crushed to about egg size by toothed rollers. These pieces are first reduced to powder and then sifted to uniform fineness. The powder is dropped through a hopper into a revolving cylinder like a coffee roaster, which is about $6\frac{1}{2}$ feet in diameter, and is surrounded by a chamber the air in which is heated by a movable furnace placed just below it. The cylinder itself revolves and, since it is provided with blades arranged in screw form, the powdered rock is well mixed with hot air and is thus thoroughly heated to a temperature between 300° and 350° F. Specifications fre-

quently permit the rock asphalt to be heated to but 200° to 250° F. When the powder is hot enough, the furnace is removed from under the heater and a cart replaces it, into which the asphalt powder is discharged and hauled to the street. The powder will retain its heat for several hours and so admits of being carted long distances without losing its heat, thus doing away with the necessity of having roasters at the point where the surface is to be laid, as was at one time the practice. For the best results, the mixture should be delivered upon the street at a temperature of not less than 250° F., although specifications sometimes permit a temperature of but 190° F.

The heated powder is spread upon the concrete base to a uniform thickness about 40 per cent greater than that required for the finished pavement. This must be done with great care in order that the material, which while hot has a great tendency to consolidate, may not be denser in one spot that another. The material is compacted by rolling in much the same way as is described for the artificial asphaltic paving compound, except that as a rule the natural rock asphalt is not consolidated to so great an extent as is customary in laying the artificial mixture. The evidence of this is that a rock asphalt pavement will continue to shrink in thickness under traffic for a year or two; while the artificial mixture shrinks but little, if any, after completion.

912. The general appearance of the completed pavement is much the same as that of the pavement made of the artificial mixture, except that the European rock pavements are lighter in color. The claim is that European natural rock asphalt pavements are more slippery and less susceptible to changes in temperature than are American artificial asphalt pavements.

Not infrequently the term rock asphalt pavement is inappropriately applied to a pavement made of an artificial mixture of sand and of asphalt extracted from a natural rock.

ART. 4. ASPHALT-BLOCK PAVEMENTS

913. There are two general forms of asphalt pavements, the sheet or monolithic and the block. Three forms of the first have been fully described in the three preceding articles. The asphalt-block pavement is constructed by first molding rectangular blocks composed of asphaltic cement and crushed stone, and then placing these blocks side by side upon a gravel or concrete foundation. In 1909

there were in this country about 5,500,000 square yards of asphalt block pavement, see page 320.

Fig. 163 shows a perspective view and cross section of a carriage way and foot way paved with asphalt blocks.

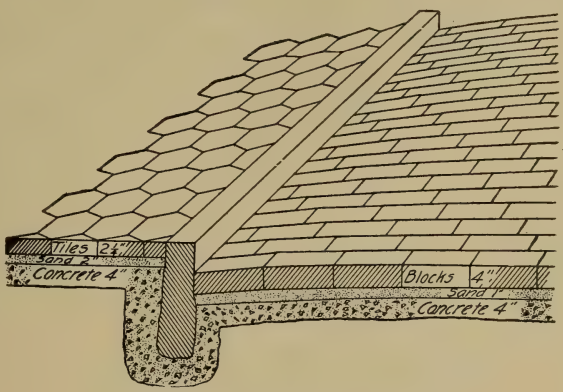


FIG. 163.—ASPHALT-BLOCK PAVEMENT.

914. THE BLOCKS. At first crushed limestone was used, but now the blocks are made with crushed trap, granite, or gneiss. The asphaltic cement is mixed substantially as for sheet pavements. The proportions employed in making the blocks vary slightly with the climate, and considerably with the fineness of the crushed stone; but are about as follows:

Asphaltic cement	6.5 to 8 per cent
Limestone dust	10 " 15 " "
Crushed stone	67 " 78 " "

Since the blocks contain larger fragments than sheet pavements, they contain a smaller per cent of voids, and hence can be made with a slightly smaller per cent of bitumen.

The ingredients are mixed and heated about as for sheet pavements, and are then molded while hot under heavy pressure. Formerly the blocks were made $5 \times 12 \times 4$ inches deep; and later they were $4 \times 12 \times 3$ inches deep, and also $5 \times 12 \times 3$ inches deep; but the blocks are usually 5 inches wide, 12 inches long, and 2, $2\frac{1}{2}$ or 3 inches deep according to the traffic conditions. Tiles are made now $8 \times 8 \times 2$ inches deep; and also with a hexagonal top surface having the same area as the square tile. The blocks are used for carriage ways, and the tiles for foot ways.

The blocks are usually moulded under a pressure of about 2

tons per square inch; and must be manufactured at such a temperature that the materials will press together in a mass having a specific gravity of not less than 2.5 if made of trap, and of not less than 2.35 if made of limestone.

915. The blocks are laid on a sand cushion or on a half-inch mortar bed on a portland concrete foundation—recently the latter is more common. After the blocks are laid, the surface of the pavement is covered with clean, fine sand or hard fine stone screenings, which are swept into the joints. The joints are not usually filled with a bituminous cement, as the blocks are malleable, and therefore travel soon seals the joints and makes the pavement practically water-tight.

916. COST. Table 54 shows the cost of asphalt block pavements in several representative cities.

TABLE 54

COST OF ASPHALT BLOCK PAVEMENTS *

Laid in 1912

LOCALITY.		Amount Laid in 1912 Sq. Yd.	CONCRETE BASE.		Depth of Blocks.	Averate Cost including Base and Grading per Sq. Yd.
State.	City.		Thickness.	Proportions.		
New York	Jamestown	13 408	5″	1 : 2½ : 5	.....	$2.94[1]
"	Niagara Falls	56 619	5	1 : 3 : 6	.....	3.20[1]
"	Port Chester	7 117	4½	1 : 3 : 6	2″	2.13[2]
"	Rye	9 800	5	.....	2½	2.56
"	Rye	18 500	4	.....	2	2.20
New Jersey	W. New York	4 800	4½	1 : 3 : 5	3	2.65
Ohio	Ashland	3 800	5	1 : 2½ : 5	2	1.94
Michigan	Highland Park	5 083	6	1 : 3 : 5	2½	2.25[1]
"	Mt. Clemens	19 000	5½	1 : 3 : 4	2½	2.08
Georgia	Savannah	51 800	.....	.....	.....	1.73
"	Way Cross	6 000	.....	.....	.....	2.10
Canada	Kingston	5 992	4	1 : 3 : 6	2½	2.95
"	Toronto	13 000	4	1 : 3 : 7	.....	3.42
"	Regina	6 185	.....	.....	.....	2.65

[1] Includes curbs.

[2] Does not include curbs.

* *Engineering and Contracting*, Vol. 39 (1913), p. 373.

917. MERITS AND DEFECTS. The *advantages* claimed for a pavement of asphalt blocks over a continuous asphalt sheet are: 1. It is less slippery, owing partly to the joints and partly to the roughening of the surface due to the use of a hard crushed stone. 2. It can be laid like any block pavement, and at the same time has almost the continuity of a sheet asphalt pavement. 3. It can be laid in cities where there is no asphalt plant. 4. It can be repaired by removal of individual units by common labor without expensive

plant and expert labor. 5. Having numerous joints, it is free from irregular and unsightly contraction cracks.

The *disadvantages* of an asphalt block pavement in comparison with a continuous asphalt sheet are: 1. Its first cost is more, since the wearing coat of the block pavement is 2 inches or more thick, while that of the continuous sheet is at most only 2 inches. 2. The edges of the blocks chip off, and the pavement wears rough. 3. It is slightly more noisy. 4. Owing to its numerous joints, it is less sanitary. 5. It is more expensive to clean. 6. Unless bedded with unusual care, the blocks have a tendency to crack. 7. It is less durable, particularly under heavy or even moderate traffic. 8. The blocks are not rigid, and do not hold their shape as well as other paving blocks; and hence the pavement is not as easy to repair as other block pavements.

CHAPTER XVII

BRICK PAVEMENTS

920. A brick pavement consists of brick set on edge on a suitable foundation—either concrete, gravel, or native soil. Brick pavements have been used in Holland for perhaps a century, and to a much less extent and for a shorter period in northern England. Brick pavements were first used in the United States in 1870 at Charleston, W. Va., a place having a population of 12,000. An experiment was tried with a short section—less than a block;—and in 1873 a block on the principal business street was laid with a good quality of building brick, and remained in service until 1909—36 years. A block of brick pavement, laid in 1875 on a leading business street of Bloomington, Illinois, a place of 20,484 population in 1890, though constructed of an inferior building brick made of a superior clay, continued in service for 20 years.

At present brick is the chief paving material employed in most of the smaller cities of the Mississippi Valley, and it is used extensively in many of the larger cities in that territory. In all parts of this country, the use of brick for residence streets and light traffic business streets is rapidly increasing. For the relative amount of brick pavements in use, see page 320. Notice that in yardage of what may be called durable pavements, brick ranks second. There are in this country nearly two hundred plants devoted to the manufacture of paving brick, some having annual outputs of 60,000,000 to 100,000,000 bricks.

921. The term brick pavements will be used in this chapter as including the brick wearing coat of both rural roads and city streets. The discussion will primarily be made with reference to city pavements, since in extent they exceed rural roads; but later brick-paved rural roads will be considered.

ART. 1. THE BRICK

922. A paving brick is simply a brick which, owing to careful selection of the clay and to skilful manufacture, is so hard and tough that it will resist the crushing and the abrading action of the travel.

923. THE CLAY. Three distinct classes of clay may be employed in the manufacture of paving brick: surface clays, impure fire clays, and shales. Surface clays are almost exclusively used for the manufacture of building bricks; and are not ordinarily suitable for making paving bricks, since it is practically impossible to burn them hard enough without their losing their shape. On account of its infusibility, pure fire clay is unsuitable for making paving brick, the brick being expensive to burn and lacking density, hardness, and strength; but quite impure fire clay makes a fair quality of paving brick, although the process of manufacture is comparatively expensive. Bricks made from impure fire clay are usually light in color, varying from cream to buff, and ordinarily are quite porous, absorbing from 2.5 to 5.0 per cent of water. Most paving bricks are made from shale,—an impure, hard, laminated clay which has been subjected to great pressure by the superincumbent earth strata. Shale is widely distributed, and usually makes a better and cheaper paving brick than either surface or fire clay, although some fire clays make excellent paving bricks.

The different classes of clay so shade by imperceptible degrees one into the other that it is impossible sharply to discriminate between them. Surface clays are soft and unconsolidated, and are found at or near the natural surface. Shales are dense and rock-like; but are easily reduced to powder, and are readily worked into a plastic mass when mixed with water. Shale is often incorrectly called soapstone, from which it differs in nearly every respect. Shale is also frequently, but erroneously, called slate, from which it differs only slightly in origin and composition; but slate, unlike shale, can not be rendered plastic by mixing it with water. The only method of distinguishing between shale and impure fire clay, except by a kiln test, is the fact that shale gives a conchoidal fracture while fire clay does not.

924. Chemical Composition. It is not wise to enter into any extended consideration of the chemical composition of brick clays, since the subject is very complicated, and since the engineer is

interested only in the physical properties of the finished product and should not attempt to prescribe the materials or to limit the methods employed by the manufacturer.

925. Physical Properties. A chemical analysis of a clay may furnish sufficient evidence upon which to condemn it for brick-making purposes, but never enough for its indorsement. The following physical properties are important factors in determining the value of a brick clay: 1, its plasticity; 2, the amount of water required to make a plastic mass; 3, the amount of shrinkage, both in burning and in drying; 4, the rapidity of drying and also of burning; 5, the temperature of incipient and complete vitrification; 6, the density before and after burning; and 7, the strength of the burned brick.

926. Manufacture of the Brick. Soft, homogeneous clay may be run through rollers, to crush the lumps, and from the crusher it may go directly to the moulding machine; but it is usually desirable to run it first through a pug mill, where it is mixed and worked with water into a plastic mass. Hard clays and shales are usually reduced to a powder in a dry pan, which consists of two heavy rollers or wheels running in a revolving pan having a perforated bottom. It is important to have the clay finely pulverized, because it will then fuse at a lower temperature, and also because fineness is necessary to the production of an even and close-grained texture which conduces to make the brick tough and impervious. The powdered clay is screened and then tempered with water in the pug mill or a wet pan. Fire clays are sometimes both crushed and tempered in a wet pan, which is similar to a dry pan except that the bottom is water tight. The wet pan gives better results than the pug mill, as the clay can be retained in the pan until it is thoroughly tempered, but as it requires a large plant, and takes more labor and power, it is not usually employed in making paving brick. The more thoroughly the clay is worked or tempered, the more uniform and better will be the brick.

927. Moulding. Paving brick are now made by the stiff-mud process. The moulding is done by an auger machine which forces the tempered clay or stiff mud through a die, thus giving a continuous bar of compressed clay. Fig. 164 shows an auger brick-moulding machine. At the right is the auger machine, in the middle the bar of clay, and at the left the cutting table or the machine for cutting the bar into bricks.

Instead of an auger producing a continuous stream of clay,

reciprocating plungers are sometimes employed, which give an intermittent bar. The auger machine is the cheapest, and is almost universally used.

928. The weak point of the stiff-mud process is the laminations that must inevitably result from pushing a stream of clay through a fixed die. The friction of the sides of the die will cause differential speeds in the flow of the clay, and these variations must necessarily result in laminations in the clay bar. If the air has been expelled

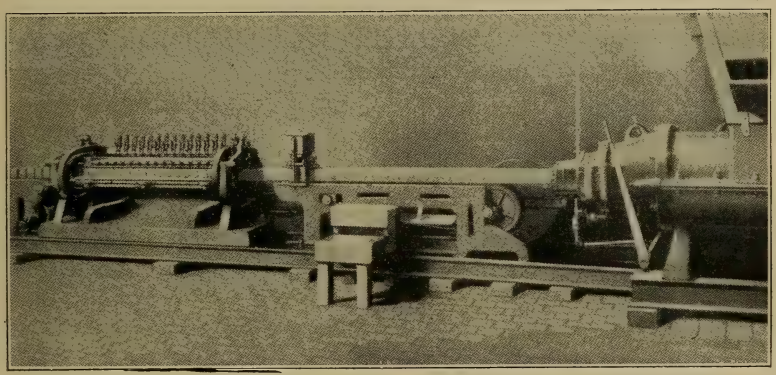


FIG. 164.—AUGER BRICK-MOULDING MACHINE.

from the clay by the pug mill, these lines can be largely closed up again by a properly shaped die, and a first-class brick will result in which the laminations will be inconspicuous and of no importance; but if the air has not been expelled, or if the tapering former and the die are not properly designed, there will be a number of concentric lines that divide the cross section of the brick into a series of shells or concentric cylinders which greatly weaken the brick. These laminations vary with the character and the condition of the clay; and as a rule, the more plastic the clay the more prominent the laminations.

929. *Cutting the Brick.* Formerly the size of the die was such as to give a bar of clay about $4\frac{1}{4}$ by $2\frac{1}{2}$ inches, which the automatic machine cut into lengths of about $9\frac{1}{4}$ inches by forcing a wire through it, thus producing what is called an end-cut brick. But now the die is usually a little greater than $8\frac{1}{2}$ by 4 inches, the excess depending upon the shrinkage of the clay in drying and burning, and the bar is cut into sections $3\frac{1}{2}$ inches thick, thus producing a side-cut brick. Substantially all paving brick are now side-cut.

930. Kinds of Brick. The first brick made especially for paving purposes was a square-edged side-cut brick with plane sides; but now several kinds or forms are in use.

931. *Re-pressed Brick.* A re-pressed brick is one that after being moulded is subjected to a heavy pressure. The re-pressing makes the brick more symmetrical in form and of better appearance.

In the early history of paving brick industry, it was claimed that one of the advantages of re-pressing was that it enabled the manufacturer to form grooves in the faces of the brick which facilitated the introduction of the joint filler and also increased the power of the filler to hold the brick in place in the pavement. Fig. 165 shows three forms of grooved paving brick.

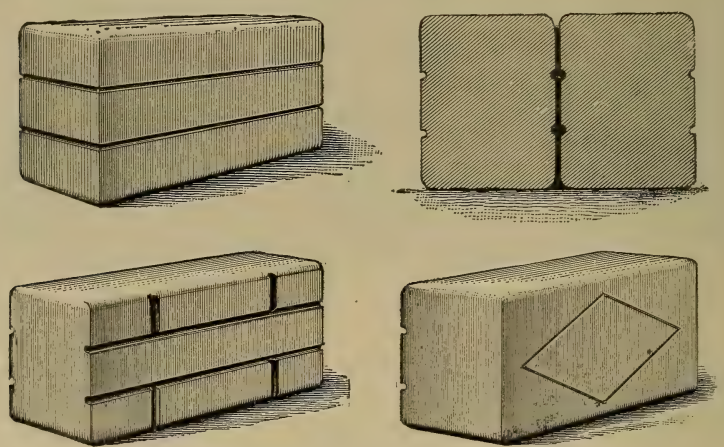


FIG. 165.—OLD-STYLE GROOVED PAVING BRICKS.

The above form of brick proved undesirable, since the joints between the bricks when set or laid in the pavement were so narrow that it was difficult to get the filler into the joints. The demand next was for a brick having projections on the side which would automatically space the joints so they could be easily and completely filled by the filler. In answer to this demand manufacturers formed lugs, or buttons, or raised letters on the side of a re-pressed brick, which served to keep the bricks a uniform distance apart and thus made joints into which the filler could easily be poured or swept. Fig. 166 shows re-pressed paving bricks which are much used.

932. Even though re-pressed under a great total pressure, the re-pressing does not increase the density of the brick. In fact the re-

press invariably increases the volume of the brick. The reasons for this are: 1. The box in which the brick is re-pressed must be slightly larger than the die-moulded clay block, so that the block can be easily dropped in; and hence re-pressing compresses the block in one direction, but expands it in the other two. 2. For

FIG. 166.—MODERN RE-PRESSED PAVING BRICKS.

practical reasons the re-pressed block must have rounded edges; and the forming of the round edges disrupts the original structure and doubtless opens up some of the laminations. However, in 1916, a few manufacturers began to make re-pressed brick with square edges. The practice seems to have been abandoned. 3. The formation of the lugs or buttons, or the making of the raised or sunken letters breaks the original bond of the clay and opens up the laminations.

Experiments show that bricks not re-pressed are stronger and freer from structural defects than re-pressed brick. The cost of re-pressing is about 2 cents per square yard of pavement. There is little or no advantage to compensate for the decreased strength and increased cost due to re-pressing.

933. A marked disadvantage of a re-pressed brick is that it has rounded edges, which makes it impossible to maintain the joint level full of filler. The filler chips out of such a joint much more easily than a joint between square-edged bricks. Re-pressed paving bricks were almost exclusively used for a quarter of a century.

934. *Wire-cut Lug Brick.* In 1910 a method of cutting the bar of clay into bricks was introduced which gives a square-edged brick having on one of its faces four lugs integral with the body of the brick, and also having a groove adjacent to each lug. The lugs project $\frac{3}{16}$ of an inch, which insures a joint at least $\frac{3}{16}$ of an inch wide; but in 1918 the lugs are to project only $\frac{1}{8}$ of an inch, which will give a minimum joint of $\frac{1}{8}$ inch. The brick also has a double bevel or bulge of $\frac{3}{32}$ of an inch at each end, which insures an end

joint at least $\frac{3}{16}$ of an inch wide at the top and bottom of the end joint. Fig. 167 shows this form of brick; and Fig. 168 shows such brick laid in the pavement.

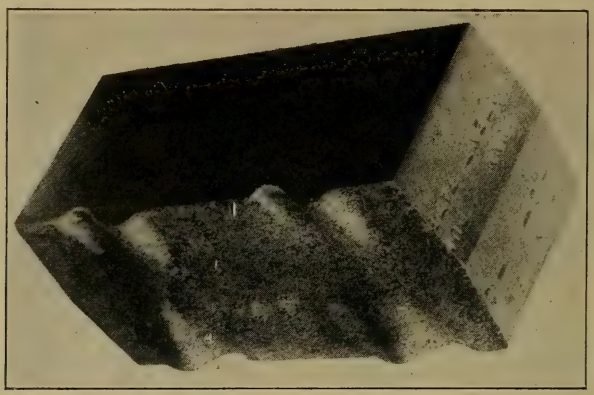


FIG. 167.—WIRE-CUT LUG PAVING BRICK.

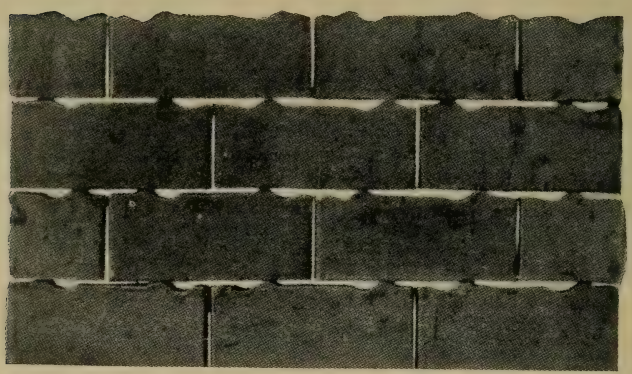


FIG. 168.—WIRE-CUT LUG BRICK IN PAVEMENT.

Fig. 169, page 481, shows the machine for cutting the bar of clay into wire-cut lug bricks. The clay is cut by forcing a wire horizontally through the bar, the wire being guided by narrow slots in plates above and below the clay. The slots on one side of the brick are wavy and form the lugs; while the slots on the other side are straight and form a plane surface.

The advantages of the wire-cut lug brick are: 1. There are no new laminations. 2. The lugs space the bricks when laid in the pavement so as to make joints of uniform width and the beveled ends

and the grooves on the vertical faces make it easy to fill the joints completely. 3. The square edge of the brick makes a joint that holds the filler better than the round-edge of the re-pressed brick, since the filler does not feather out at its wearing surface. 4. The wire-cut face is rougher than the smooth face of the re-pressed bricks, and therefore the joint filler adheres better.*

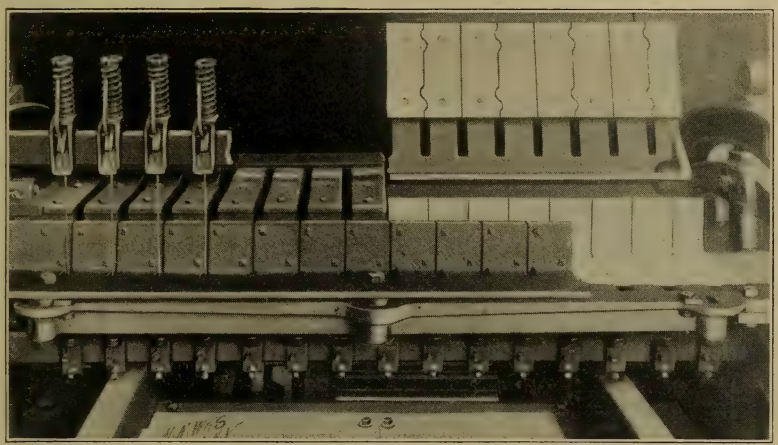


FIG. 169.—MACHINE FOR CUTTING WIRE-CUT LUG BRICK.

On the other hand, the wire-cut lug bricks require considerably more filler than the re-pressed brick.

The wire-cut lug brick is patented; but many manufacturers are licensed to make it, and it is sold in unrestricted competition. Something like three fourths of all the paving bricks used east of the Mississippi river are of this type. Many manufacturers make both the wire-cut lug and the re-pressed paving brick.

935. *Vertical-fiber Brick.* The vertical-fiber brick is one cut from a die-moulded bar of clay by wires traveling in straight parallel slots, which is laid in the pavement with the wire-cut face up, and hence the wear comes upon the end of the laminations or fibers. Lugs are formed on one side of the brick by notches or grooves in one side of the die. Apparently this form of brick is made only by members of the Western Paving Brick Manufacturers Association, and promoted by it.

The advantages officially claimed for this type of brick are: 1.

* For experimental data proving this, see *Engineering Record*, Vol. 69 (1914), p. 607.

It is not patented, and therefore can be made by any manufacturer without paying royalty. 2. The depth of the brick as laid in the pavement can easily be changed by simply changing the spacing of the cutting wires. 3. The brick can be set in the kiln so that all kiln marks come upon the vertical surfaces, and hence leaves the bedding and wearing faces free from such marks and makes a smoother pavement. 4. In the vertical-fiber brick the wear comes upon the end of the laminations, instead of on the sides as in other kinds. 5. The wire-cut surface gives a good foothold for horses. 6. If a bituminous filler is used, the wire-cut surface aids in retaining a carpet of bituminous material on the surface.

Of the above claims 1, 2, 3, and 4 must be admitted as being true; but there is a great difference of opinion as to the importance of the advantage claimed. Claim 5 is of doubtful value, since all brick pavements afford a satisfactory foothold for horses. Claim 6 is a disadvantage rather than an advantage, since the smoother the surface of a brick pavement the better, and since at best a thin film of bituminous cement can not endure long on a brick pavement (see § 579). It is a reversal of good practice to place the rougher face horizontal and the smoother vertical.

The weight given to the above claims seems to be largely a matter of locality. The wire-cut lug brick is favored by at least most of the members of the National Paving Brick Manufacturers Association, while the vertical-fiber brick seems to be preferred by the members of the Western Paving Brick Manufacturers Association. The territory of the former is east of the Mississippi river, and that of the latter west of that river. However, as only about 4 per cent of the paving bricks made in the United States are manufactured between the Mississippi river and the Rocky Mountains, this difference of opinion is not important. Many re-pressed and wire-cut lug bricks are used west of the Mississippi river.

936. *Hill-side Brick.* To afford a better foothold for horses on steep grades, a special hillside brick is made. There are two forms:

1. A brick laid with its long dimension across the street and having one edge each of its top and bottom edges chamfered, which gives a series of continuous parallel grooves running transversely across the road or street. These bricks are usually re-pressed, the chamfered corners being produced by filling up opposite edges of the mould.

2. A brick laid with its long dimension lengthwise of the road or street, and having one or more transverse grooves on each of

its two edges, thus producing a series of non-continuous parallel grooves across the road. These brick are die-moulded side-cut, the grooves being produced by metal lugs on the sides of the die. Fig. 170 shows a wire-cut lug hill-side paving brick; and Fig. 171 shows such brick in the pavement before rolling and before the application of the joint filler. Fig. 171 is a street in Toronto, Canada, on a 6 per cent grade. Sometimes a strip of hill-side bricks is laid on each side of the street with a strip of ordinary paving bricks in the center.

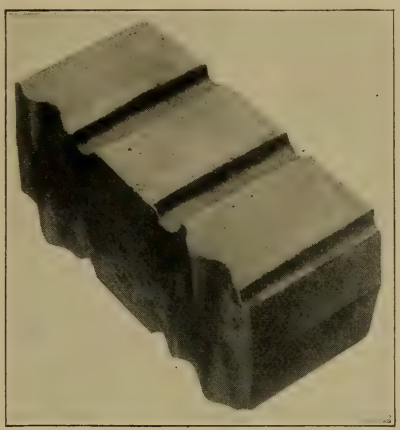


FIG. 170.—WIRE-CUT LUG HILL-SIDE PAVING BRICK.

937. After being moulded, or after being re-pressed, the bricks are placed on trucks or cars, and conveyed to the dry house. A paving brick immediately after being moulded contains 20 to 30 per cent of water; and hence thorough drying greatly facilitates the burning of the brick.

FIG. 171.—HILL-SIDE BRICK IN A PAVEMENT.

938. Burning. Paving bricks are usually burned in down-draft brick-ovens having fire pockets or furnaces built in their outer walls.

The bottoms of the kilns are perforated to allow the gases to pass through the flues, which are beneath the floor, and which lead to the chimney. The fire passes up from the furnaces into the kiln, then down through the brick to be burned to the flues, and thence to the chimney. The burning is the most critical step in the manufacture of paving brick. At first the heat is applied slowly in order to drive off the remaining water without cracking the brick. A low heat is continued until the smoke passing off shows no further signs of steam or "water-smoke," after which the fires are gradually increased until the temperature throughout the kiln is sufficient to vitrify the brick. Most shales vitrify at from 1,500° to 2,000° F.; but impure fire-clays require from 1,800° to 2,300° F. From seven to ten days are required to raise the entire kiln to the vitrifying temperature.

There has been much discussion as to the meaning of the term vitrification as applied to brick making. Literally speaking, to vitrify means to render glassy; but as applied to clay working, vitrification has come to mean incipient fusion of the particles of the clay into a new chemical compound. The degree of vitrification increases with the temperature, and the logical end of the process is complete fusion. A clay is partially vitrified if its constituents have begun to unite by heat into a compound silicate, even though it may not have a glassy fracture. The physical peculiarities which mark vitrification in a burned clay are the conchoidal fracture, the absence of pores, and the blending of the ingredients into one mass. Cracks, fissures, and cavities may be found, but porosity must not exist in a well vitrified brick; and the original particles must have begun to cohere by the bond of heat instead of the bond of plasticity. Within limits which are different for different clays, the degree of vitrification in a burned clay is measured by its ability to absorb water. A lightly burned brick will greedily absorb water, and the greater the degree of vitrification the less the water absorbed, a fully vitrified brick absorbing absolutely no water.

After the bricks have been vitrified entirely through, the kiln is tightly closed and allowed to cool very slowly. Rapid cooling renders the brick brittle; but by slow cooling they are annealed and rendered tough. Slow cooling is the secret of toughness, and the slower the cooling the tougher the brick. The annealing is frequently unduly hurried, much to the detriment of the toughness of the brick. The kiln is often cooled in three to five days, when seven to ten would materially improve the product and usually would be worth the extra cost.

With the utmost care a considerable per cent of the contents of the kiln are unsuitable for paving purposes, because of some being under-burned and some over-burned. With shale 80 to 90 per cent of first-class paving brick is a high average, while with impure fire clay 85 to 90 per cent may be produced.

939. Size of the Brick. Formerly there was considerable difference of opinion as to the best size for paving brick, some advocating $2\frac{1}{2} \times 4 \times 8''$, others $3\frac{1}{2} \times 4 \times 8\frac{1}{2}''$, and a few $4 \times 5 \times 12''$. The first size is always referred to as a brick, but the last two are sometimes called paving blocks. The last was never made in any quantity, and has been entirely abandoned. There is no conventional line by which to distinguish bricks from blocks. It was often claimed that one or the other size made the better pavement, but there is no material difference in the quality of the pavement between the different sizes.

The advantages of the building-brick size are: (1) being smaller they are more easily vitrified, and therefore a little cheaper to manufacture; and (2) brick unsuitable for use in the pavement can be more readily disposed of for building purposes, a fact which tends to cheapen the cost of the brick used in the pavement. The advantages of the block-size to the manufacturer are that there are fewer pieces to handle; and in the pavement the blocks chip or spall on the edges less than the bricks, particularly if the filler is not rigid (see § 1014). The manufacturer of the block sometimes places building brick in that part of the kiln in which it is difficult to burn blocks thoroughly (the bottom of a down-draft kiln), a process which decreases the per cent of blocks unsuitable for paving purposes, and at least partially eliminates the second advantage of the building-brick size as above. In the early history of brick paving, bricks were most in favor; but now the blocks are used almost exclusively, and usually they are called bricks.

940. Uniformity of size is very desirable to prevent confusion in buying and bidding, and particularly for convenience in making repairs. Unfortunately the sizes of building bricks and also of paving bricks or blocks vary considerably in different parts of the country.

941. The Specifications of the National Paving Brick Manufacturers Association, which have been widely adopted by engineers, prescribe re-pressed and wire-cut lug paving blocks shall be $8\frac{1}{2}$ inches long, 4 inches deep, and $3\frac{1}{2}$ inches wide, with the provision that shallower brick may be used (see § 942). The specifications of the Western Paving Brick Manufacturers Association seem

to have no standard size for vertical-fiber brick; but seem to make such brick from $3\frac{3}{4}$ to $4\frac{1}{2}$ inches wide, from 8 to 9 inches long, and $2\frac{1}{2}$, 3 or 4 inches deep, a depth of $2\frac{1}{2}$ inches seeming to be the most common.

Until 1916 the Specifications for Brick Pavements adopted by the American Society of Municipal Improvements permitted the use of either bricks or blocks; but in 1916 the specifications were amended so as to permit the use of only blocks $8\frac{1}{2}$ inches long, 4 inches deep, and $3\frac{1}{2}$ inches wide.

The width is always exclusive of lugs or buttons.

942. Thus far in the history of brick pavements, the depth of the brick has quite uniformly been 4 inches; but some engineers claim that no brick pavement ever failed through the wear on the brick, and therefore the depth of the brick should be reduced.

In 1915 a new type of brick pavement was introduced (§ 982), which would safely permit a reduction in the total thickness of the pavement. This and relative matters are discussed in § 1028.

943. TESTING THE BRICK. It is important to have a definite method of testing the qualities of any artificial material, since then all parties may know exactly the grade called for, and since the results obtained by different observers with different materials may be compared. This is particularly true of brick, since the clays differ greatly in quality, and also since a slight variation in each step of the manufacture materially affects the result. The object of testing paving brick is two-fold: (1) to determine whether the material is suitable for use in a pavement; and (2) to enable comparisons to be made between different classes of brick.

Several tests formerly employed have now been practically abandoned; but for the sake of completeness these will be briefly considered.

944. General Appearance. A critical examination of a paving brick by the experienced eye aided by a hand hammer is a fair method of determining the relative merits of different bricks of a particular kind; but unfortunately experience with one make is not of much value with brick made by a different process or of a different kind of clay, and further the results by this method of testing admit of no numerical evaluation or even of being described accurately. It is a method of selecting or inspecting rather than of testing.

The brick should be reasonably straight; and have flat sides and square corners; be uniform in size, texture and shape; and be hard, tough, and evenly burned. If the edges of the bricks are square,

they should be smooth and free from serrations or "ragging," due to friction in the die. If the edges are rounded, the radius should not exceed three sixteenths of an inch. Kiln marks or impressions from the over-lying brick in the kiln must not be more than three sixteenths of an inch deep. One face should have not less than two nor more than four projections, which should be not more than one fourth nor less than one eighth inch high, nor exceed one half square inch in area.

When broken the interior of the brick should show a uniform fracture, be free from lime, and contain no uncrushed or lumpy material, especially if such material is not united by vitrification with the remainder of the material. There should be no marked laminations.

945. Size. The brick should closely conform to the standard size (§ 941) or to the specified size. The brick from any one manufacturer should be of uniform size; and the brick for any one job should be of practically the same size. The usual specifications are as follows: "A brick shall not vary from standard or specified dimensions more than $\frac{1}{2}$ an inch in length, nor more than $\frac{1}{8}$ inch in width or depth." Sometimes it is also specified that "the bricks in any one shipment must not vary in width or depth more than $\frac{1}{8}$ of an inch."

946. Color. The color is no criterion of the value of a paving brick, when comparing bricks of various makes; but, in inspecting bricks from a single factory, the color will usually furnish a fairly safe guide as to the relative hardness, when the inspector is thoroughly acquainted with the particular manufacture. The knowledge gained regarding the relation of color and quality in inspecting one make of brick, however, can seldom be used with that of another make from a different locality, as clays vary greatly in kind and degree of color. The popular belief is that hardness is proportional to the darkness of the color of the brick, and that light color is prima facie evidence of softness. As a rule the impure fire clays make excellent paving material, although the bricks are light colored, usually buff, while shale bricks are red or brown. For a particular clay, the color of the bricks indicates the degree of heat they have received, provided they were burned with the same fuel and under the same conditions; and ordinarily the higher the heat the darker the color, and presumably the better the brick. The uniformity of the color of the interior of the brick is more important than the color of the exterior.

The color of the outside of the brick is sometimes valueless owing to the sand employed to prevent sticking in the kiln, or to the effect of sulphur in the coal used in burning, or to salt glazing. Salt glazing is a trick occasionally employed to give a dark gloss to the outside which is very attractive to the superficial observer, but which is practically worthless, since it is only skin deep and soon wears off. Salt glazing makes it more difficult to detect soft brick, and should never be allowed on paving brick.

947. Specific Gravity. In a general way, the more dense a brick the harder and stronger it is; and consequently early in the history of brick testing it was believed that a knowledge of the specific gravity would be of value in judging of the quality of a paving brick. It is now known that the specific gravity reveals nothing not determined by other tests; and further that the density depends upon the character of the clay, the kind of fuel, etc., and in no way measures the quality of the product. The specific gravity may be computed by the formula:

$$\text{Specific gravity} = \frac{Wa}{Ws - Wi},$$

in which Wa represents the weight of the dry brick in air, Ws the weight of the saturated brick in air, Wi the weight of the brick immersed in water. The specific gravity of shale brick ranges from 2.05 to 2.55, and usually from 2.20 to 2.40; and that of brick made from impure fire clay ranges from 1.95 to 2.30, and generally from 2.10 to 2.25.

948. Crushing Strength. The results for the crushing strength vary more with the details of the method employed than any other test of paving brick. There is no standard method of making this test. For experimental data showing the marked effect of the different methods of testing, see the author's Treatise on Masonry Construction, tenth edition, § 10–17, and § 78–81.

Tests on cubes cut from paving brick show that the best paving brick have a crushing strength of 10,000 to 20,000 lb. per square inch. This is the crushing strength when the load is applied uniformly over the surface of the test specimen; but if the pressure is applied to only a small part of the upper surface of a brick, the strength will be much greater.* Any brick that is likely to be

* See Baker's Masonry Construction, tenth edition, § 657.

accepted for paving purposes by any of the tests hereafter described, is in no danger of being crushed by the pressure of the wheel of a vehicle. For example, the surface of contact between a wheel having a $1\frac{1}{2}$-inch tire loaded with half a ton is about one half square inch, which gives a pressure on the brick of only about 2,000 lb. per square inch.

If the crushing strength could be easily and accurately found, it would be of value in determining the relative strength, and hence would be useful in comparing the quality of different brick; but owing to the difficulty of making the experiments and to the uncertainty of the results, the test has been abandoned.

949. Absorption Test. In the early days of the paving brick industry, many of the brick used were so porous and brittle that it was feared they would be disintegrated by the action of frost; and consequently the absorption test was employed to eliminate porous brick. Subsequent tests by repeatedly freezing and thawing paving bricks showed that any brick which was likely to be accepted for paving purposes would not be appreciably injured by the action of frost. There are probably two elements that prevent frost from seriously injuring even a soft paving brick; viz.: (1) the cushioning effect of the air remaining in the pores of the brick, and (2) the strength of the brick may be greater than the disrupting effect of the frost. Alternate freezing and thawing might injure a non-vitrified brick, which is not only very porous but is also deficient in strength; but such a brick would be rejected for paving purposes as the result of a casual inspection. The absorption test is no longer regarded of importance as measuring the ability of the brick to resist freezing and thawing.

Different bricks vary widely in their *rate* of absorption. For example, one brick absorbed in one day 80 per cent of its total amount, while another absorbed only 8.7 per cent; and two other specimens absorbed 71.8 and 19.5 per cent respectively in the same time. The absorption of whole brick is slightly less than that of half brick, and the absorption of half brick is considerably less than that of small chips. For the above reasons and for other minor ones, results for the absorptive power are likely to be untrustworthy.

950. Transverse Strength. This is determined by resting the brick upon two knife-edges and applying a steady pressure on the upper side of the brick through a third knife-edge placed midway between the other two. The results are expressed in terms of the

modulus of rupture, which is computed by the following formula:

$$R = \frac{3\,W\,l}{2\,b\,d^2},$$

in which R represents the modulus of rupture in pounds per square inch, W the breaking load in pounds, l the distance between supports in inches, b the breadth of the brick in inches, and d the depth of the brick in inches. The brick may be tested edgewise or flatwise, although the former is usually the better method, since then W is larger. The knife-edges should be rounded transversely to a radius of about one sixteenth of an inch and longitudinally to a radius of about 12 inches, to secure better contact and to prevent the brick from being crushed at the edges. Some authorities recommend grinding opposite edges of the brick to parallel planes, but this is a useless expense. If the brick is warped, the contact between the brick and the knife-edges can easily be made entirely satisfactory by placing pieces of metal under the blocks carrying the lower knife-edges, or by shifting the brick longitudinally, or by turning it.

The modulus of rupture of bricks that have given excellent service in a pavement varies from 1,500 to 3,500 lb. per square inch, usually from 2,000 to 3,000. Owing to apparently unavoidable variations in the structure of the brick, it is not possible to attain closely concordant results in making this test; and with the utmost care in selecting the brick and in making the tests, the variation from the mean ranges from 8 to 30 per cent, and on the average is about 20 per cent.

The cross-breaking test furnishes a means of comparing the toughness of various kinds of paving brick. The uniformity of the results for any particular kind of brick indicates its structural soundness, freedom from air checks, etc., and shows whether the material has been properly treated in the various stages of manufacture. The transverse strength indicates the resistance of the brick to cross breaking when laid in the pavement on an unyielding and uneven surface; but this element is not entitled to much consideration, since brick are seldom thus broken in the pavement, at least not until nearly worn out.

The test is comparatively easy to make, and is a valuable check upon the rattler test (§ 951).

951. Rattler Test. This test is made by rolling or tumbling the bricks in a foundry rattler, i. e., a revolving cast-iron barrel; and it

greatly exceeds in importance all the other tests combined. It imitates more closely than any other, the impact due to the horse's hoofs and shoes, and to the bumping of the vehicle wheels, and also the abrasion due to the slipping of the horse's feet and the sliding of the wheels. This test could with propriety be called an impact and abrasion test. The result of the test is jointly dependent upon the toughness of the brick—its ability to resist shock,—and its hardness—its ability to resist abrasion.

To make this test of any scientific value, it is necessary to have some standard method of conducting the experiments. Several methods of standardizing this test have been proposed. The first test was made by the author.* Brick that had seen service in a pavement and pieces of well-known natural stones used for paving purposes, together with small pieces of scrap cast iron, were rolled in a rattler. Shortly after being proposed, this method was quite widely adopted; but it did not give satisfactory results, chiefly because the original experiments were made with a rattler having wooden staves, while subsequent tests were made with rattlers having cast-iron staves. The method was objectionable on account of the trouble and expense of preparing the test pieces of natural stone. Later each of four radical modifications of the test gained prominence in succession for a time. Finally it was found that seemingly unimportant details materially affected the results, as, for example, the chemical composition of the cast iron in the staves and abrading material, the stiffness of the staves, the frequency of renewal of the staves and abrading material, the speed of rotation, the method of driving the rattler, etc.

952. In 1910 after a very elaborate series of tests, the National Paving Brick Manufacturers Association proposed specifications which set forth in great detail the method of constructing and using the rattler; and in 1915 substantially these specifications were adopted by the American Society for Testing Materials, and they have been generally accepted as the standard.†

Fig. 172, page 492, shows the standard rattler and abrasive material. The latter consists of two sizes of cast iron spheres, the larger weighing 7.5 lb. each and the smaller 0.95 lb. The total abrasive

* Durability of Paving Brick, by Ira O. Baker. pp. 46, 5″ × 8″. T. A. Randall & Co., Indianapolis, Ind., 1891. Out of Print.

† Proc. Amer. Soc. for Testing Materials, Vol. XV, Year Book 1915, Report of Committee C–3, pp. 396–407. Copies of complete specifications for the inspection and testing of paving brick may be had by addressing Secretary Amer. Soc. for Testing Materials, Philadelphia, Pa., or Secretary National Paving Brick Mfrs. Assoc., Cleveland, Ohio.

charge consists of 10 large spheres and 245 to 260 small ones, the collective weight being as nearly as possible 300 lb.

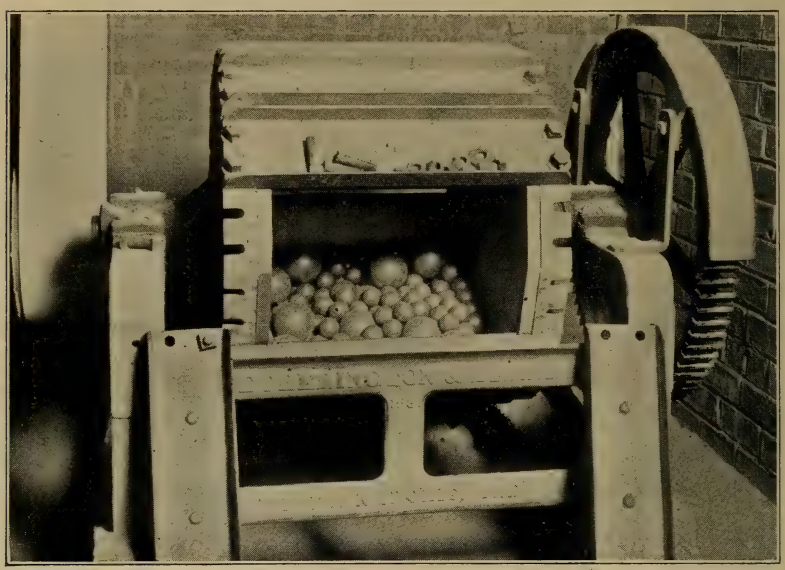


FIG. 172.—STANDARD BRICK RATTLER.

In consulting the literature concerning tests of paving brick, it is necessary to carefully distinguish between the present and the former standard. The latter gives the smaller loss.

953. *Making the Test.* To make the rattler test, the bricks are thoroughly dried, weighed, placed in the rattler, and turned 1,800 revolutions at a speed of 30 revolutions per minute, and then weighed. The percentage of loss indicates the quality of the brick.

Fig. 173 shows the brick charge before and after testing. Ten brick of the so-called block-size constitute a charge.

954. The object of the rattler test is twofold, viz.: (1) to determine whether the bricks are tough enough for use in a pavement, and (2) to determine whether the material is uniform in quality. The first is determined by the average loss of a charge, and the second by the uniformity of loss of the several bricks. Uniformity of wear is an important quality, for a single soft brick may wear so as to make a hole in the pavement, and then each passing wheel will rapidly destroy adjacent bricks even though they themselves are of excellent quality.

To determine the uniformity of wear, the rattler test should be

so conducted as to find the loss of each brick. This requires the marking of the bricks so they can be identified after being tested.

FIG. 173.—BRICK CHARGE BEFORE AND AFTER TESTING.

955. *Marking the Brick.* There are several schemes in use for marking the several bricks of a charge.

The following method is used by William H. Howell, Engineer of Streets and Highways, Newark, N. J.* "The holes may be made with a small cold chisel, after a little experience, in twenty to twenty-five minutes." Fifteen holes are required.

1. One drill hole on one side.
2. One drill hole on one edge.
3. One drill hole on each side.
4. One drill hole on each edge.
5. One drill hole on one end.
6. One drill hole on each end.
7. Two drill holes on one side.
8. Two drill holes on one edge.
9. One drill hole each on one edge and one end.
10. Blank.

The method shown graphically in Fig. 174, page 494, was proposed by C. A. Baughman, Instructor in Civil Engineering, Iowa State College.† The holes are made with a small diamond drill,

* Proc. Amer. Soc. of Municipal Improvements, 1911, p. 95.
† *Engineering and Contracting*, Vol. 44 (1915), p. 470.

and are about one eighth of an inch deep. Eighteen holes are required.

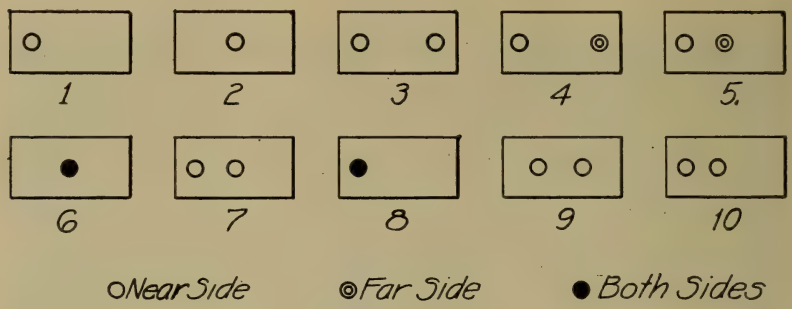


Fig. 174.—Baughman's Method of Marking Brick.

Fig. 175 shows the method proposed by Mr. B. L. Bowling, Assistant in Road Laboratory, University of Illinois, for marking wire-cut lug brick. Brick No. 10 is not marked. Notice that only nine holes are required. The holes are one fourth of an inch in diameter, and one fourth of an inch deep; and can be made with a compressed-air percussion drill in about forty minutes.

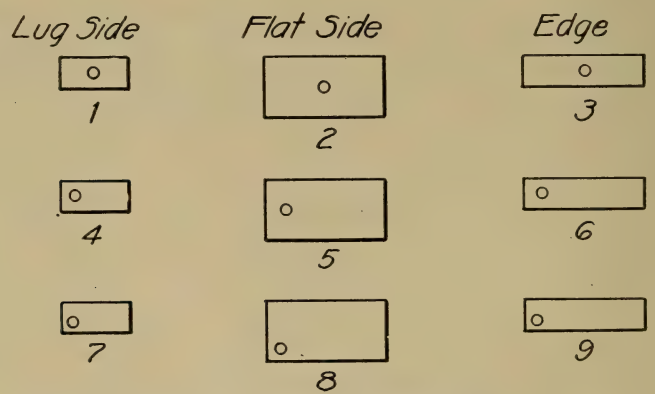


Fig. 175.—Bowling's Method of Marking Wire-cut Lug Brick.

Of course, determining the loss of each brick in the charge requires extra time in marking and weighing; but it is believed that the additional cost is abundantly justified. It is sometimes claimed that the brick can not be marked so as to identify them after the test without weakening them and increasing the loss in the rattler;

but it has been proved that this is not true to an appreciable extent in any of the three methods of marking mentioned above.

956. *Limit of Loss.* The standard specifications do not prescribe any limit for the permissible loss; but distinctly state that such limit shall be determined by the contracting parties. The standard specifications give "the following scale of losses to show what may be expected of tests executed under the foregoing specifications:

For bricks suitable for heavy traffic.....22 to 24 per cent.
For bricks suitable for medium traffic.....24 to 26 per cent.
For bricks suitable for light traffic.....26 to 28 per cent.

"Which of these grades should be specified in any given district and for any given purpose, is a matter wholly within the province of the buyer; and should be governed by the kind and amount of traffic to be carried, and the quality of paving bricks available."

957. The limit that should be specified for the average loss in any particular case will depend upon the following: (1) the traffic to be carried, (2) the ordinary quality of the brick available, (3) the expense to be incurred in culling or selecting the brick, (4) the size of the brick or block, (5) the form of the edge of the brick, (6) the minimum dimension of the brick, (7) the uniformity of the loss.

1. The amount and character of the travel may be such as to make it unwise to specify the highest grade of brick.

2. The locality may be such that the ordinary paving bricks are of a high quality, and hence no appreciable increase of expense will be incurred by requiring a high grade of brick, i. e., a low rattler loss. For example, in a certain year the average loss of all the bricks submitted to a testing laboratory in an eastern state was 18 per cent, and several lots of each of three brands gave an average loss of only 14.3 per cent; but on the other hand, all the bricks submitted in a year to a laboratory in a western state gave an average loss of 22.56 per cent, with only three charges having a loss less than 17 per cent. In some localities, specifying a small loss may limit competition and thus increase the price of the bricks.

3. If the bricks available are not uniformly good, and if the service required of the proposed pavement is severe, it may be wise to specify a quality which will require careful selection and possibly include only a comparatively small percentage of the kiln run. Of course, the last method is expensive, because of the cost of culling, and also because the better bricks should bear part of the possible loss on the rejected bricks.

4. The limit to be set for the loss depends upon the size of the bricks or blocks, i. e., whether the pavement is to be built of bricks or blocks. However, as but few bricks are now used in pavements, this phase of the subject is not important. Apparently the relative loss of bricks and blocks has not been determined with the 1910 standard rattler; but in view of data obtained with the former standard, some authorities permit a differential of 2 per cent in favor of brick in comparison with block.

5. The limit varies also with the form of the edge or corner of the brick. If a brick has square corners, it will lose more in the rattler than one having rounded corners. The standard re-pressed brick has corners of a $\frac{3}{16}$-inch radius, and the absent corner represents about $1\frac{3}{4}$ per cent of the volume. Therefore a square-cornered brick could lose $1\frac{3}{4}$ per cent in the rattler before being on a par with a standard round-edge re-pressed brick. For this reason, some claim that the former should be allowed 1 or 2 per cent greater rattler loss than the latter. The Illinois Highway Commission allows the standard wire-cut lug brick a differential of 1 per cent over the standard re-pressed brick.

6. The limit should depend upon the minimum dimension of the brick. Since the general use of a concrete foundation for brick pavements, and particularly since the introduction of the semi-monolithic and the monolithic construction, there has been a marked tendency to use a shallower brick. Formerly paving brick were quite uniformly 4 inches deep; but now, bricks of various depths are being used, $3\frac{1}{2}$, 3, $2\frac{1}{2}$ inches (§ 1028). The prescribed limit of rattler loss should be less the thinner the brick. The loss in the rattler is mainly due to the edges being worn or broken off (Fig. 173, page 493). The central portion of a brick loses almost nothing except at its edges or corners. A brick $3\frac{1}{2} \times 4 \times 8\frac{1}{2}$ inches has 64 inches of edges or corners, while a brick $3\frac{1}{2} \times 3 \times 8\frac{1}{2}$ inches has only 60 inches of edges, or $6\frac{1}{4}$ per cent less. Apparently then for this reason a difference should be made in the limiting loss between a 4-inch and a 3-inch brick. Further, it is claimed that the form of the rattler test is unjust to a brick thinner than the $3\frac{1}{2} \times 4 \times 8\frac{1}{2}$-inch standard, since if a thin brick becomes bridged in the rattler it is much more likely to be broken than a thicker one. The Ohio Highway Department takes account of these two factors, at least approximately, as follows: It specifies a loss for standard 4-inch brick of not more than 22 per cent, and then inserts the following clause in its standard specifications: "If other than standard sized

blocks are required by the plans or specifications, the average rattler loss allowed shall be 22 per cent multiplied by the ratio of the volume of the standard block to the volume of the block specified, less 2 per cent." For another method of testing 3-inch brick, see the second paragraph of § 960.

7. The limit depends also upon the uniformity of loss of the several bricks of a charge. A low rattler loss with a wide range will probably not give as durable a pavement as a larger average loss with a narrower range. A single soft or brittle brick will soon wear below those adjacent to it, and then each passing wheel, particularly a steel-tired one, in dropping into the depression chips and crushes the adjoining bricks (however good they are) and tends to destroy the pavement. The Illinois State Highway Department recognizes this principle, and specifies that the average loss of wire-cut lug bricks may be 23 per cent provided the individual bricks have losses between 17 and 27, or 25 per cent provided the individual losses are between 20 and 28, or 27 per cent provided the individual losses are between 23 and 29. The degree of uniformity of the rattler loss depends upon the quality of the bricks, but chiefly upon the care and skill employed in culling the brick at the kiln. For data on the degree of uniformity obtained in practice, see § 959.

958. *Loss Found in Laboratory.* It is presumable that the paving brick sent to a laboratory to be tested are usually samples proposed for use in a pavement; and hence the average losses are instructive as showing the quality of the material available in that locality, and the range of loss in any charge is evidence of the skill employed in culling the brick at the kiln. Sometimes the sample may be sent to obtain for the manufacturer information concerning some point in manufacture; but usually the manufacturer will make such tests at home, and hence the samples tested at a public laboratory may be considered fairly representative. However, the results obtained in any state or city laboratory will depend somewhat upon the maximum rattler loss permitted by the official specifications of that state or city. For example, if one state or city specifies a lower rattler loss than another state or city, manufacturers when shipping brick for work under the former specifications are likely to select a better quality or cull the bricks more carefully than when shipping to the other state or city.

In 1916 the Illinois Highway Department tested 59 charges of re-pressed blocks, which gave an average loss of 20.9 per cent; and 71 charges of wire-cut lug brick, which gave an average loss of 19.9

per cent.* The three smallest losses for re-pressed brick were 16.8, 16.8, and 17.0 per cent; and the three smallest for wire-cut lug brick were 17.4, 17.4, and 17.5 per cent. The three least ranges in loss of the individual bricks in a charge were: for re-pressed brick 3.5, 3.8, and 3.8 per cent; and for wire-cut lug brick 4.0, 5.7, and 6.0 per cent. The three greatest ranges in loss of individual bricks were: for re-pressed bricks 25.1, 27.8, and 31.1 per cent, and for wire-cut lug bricks 23.9, 24.1, and 26.2 per cent. The last results simply show that probably some of the samples were not carefully culled, although it is well known that it is sometimes practically impossible by appearance alone to eliminate all the poor brick.

In 1916, Vermilion County, Illinois, tested 124 charges of blocks which were practically all wire-cut lug brick from a local plant. The average loss of all was 18.06 per cent. One charge had a loss between 14 and 15 per cent, 7 between 15 and 16, 27 between 16 and 17, 31 between 17 and 18, and 25 between 18 and 19. The average loss of the brick used in 8 miles of rural road was 17½ per cent. The range in the five best lots was 3.5, 3.7, 3.7, 4.1, and 4.3 per cent, and in the three worst was 21.1, 29.2, and 31.5 per cent.†

The Iowa Engineering Experiment Station in 1916 tested 85 different charges with an average loss of 22.56 per cent. The three smallest were: 16.31, 16.78, and 16.80. Twelve charges of re-pressed brick gave an average loss of 19.44; and 33 charges "that were not re-pressed" gave an average loss of 24.06 per cent, and omitting four of the largest the average is 22.33 per cent.‡ The kind of brick in the remainder of the charges is not known; and the results for individual bricks are not known.

In 1917 the Ohio Highway Commission tested 302 lots of 23 different brands of blocks 4 inches deep, the average loss of all brands being 21.14 per cent. The three smallest average losses were 17.47, 18.98, and 19.34; and the three largest were 23.95, 25.08, and 27.84. The range of average losses for the three brands having the smallest losses were respectively: 3.20 for four lots; 5.96 for 26 lots, and 10.04 for 14 lots. Apparently, no results were obtained for individual bricks.§

In one year the Maryland Roads Commission tested 19 charges of six different brands of blocks, the average being 18.7 per cent. Four

* Data from F. L. Roman, Engineer of Tests.
† Data from P. C. McArdle, Superintending Engineer, Danville, Ill.
‡ Data from R. W. Crum, in charge of testing.
§ Data from A. S. Rea, Engineer of Tests.

charges of one brand average 14.5 and three charges of another 14.3 per cent. In another year the Commission tested 12 charges of one brand which averaged 20.83 per cent, one lot was rejected, and the average for the 11 lots accepted was 20.5 per cent.*

The New York State Highway Commission in the past few years has tested many paving blocks, in one year making exactly 400 duplicate tests. For 1914–17 the average loss for wire-cut lug blocks was 21.3 per cent, and for re-pressed 20.9 per cent. The average loss in a duplicate test usually varied from about 17 to 24 per cent, with a few as low as 15 and a few as high as 27 per cent.† In consideration of the way in which the samples were obtained it is not permissible to attempt to draw any conclusions from these data as to the relative quality of re-pressed and wire-cut lug brick. The results seem to show a slight improvement in quality from year to year; and the results from several other laboratories agree with this conclusion.

959. *Loss Allowed in Practice.* The classification of losses suggested by the American Society for Testing Materials is stated in § 956. These limits have been adopted by many cities. The rattler loss allowed by the Illinois Division of Highways for wire-cut lug brick is stated in the previous section; and the permissible loss for round-edged re-pressed brick is 1 per cent less in each case.

Vermilion County, Illinois, in 1916, built 8 miles of monolithic brick rural roads, and specified that the average loss of a charge should not exceed 23 per cent, and that no single brick should exceed 27 per cent. The general average loss of the brick used was $17\frac{1}{2}$ per cent.‡ For a summary of all the rattler tests made, see the third paragraph of § 958.

The Ohio Highway Department specifies that the average loss of standard brick shall not exceed 22 per cent; and that the range shall not exceed 8 per cent. For brick thinner than the standard, a differential is allowed as stated in paragraph 6 of § 957.

The New York State Highway Department specifies a maximum average loss of 24 per cent.

960. *Changes in Test Proposed.* In the early history of brick pavements the joints were usually filled with sand, and hence the wear of the brick in the pavement was due largely to impact; and therefore a form of rattler test was adopted in which the wear was

* Data from H. G. Shirley, Chief Engineer.
† Data from H. E. Breed, First Deputy Commissioner.
‡ *Engineering Record*, Vol. 74 (1916), p. 678.

largely due to impact. But now the joints of brick pavements are usually filled with grout or at least a comparative hard bituminous cement; and hence the wear on the brick in the pavement is mainly abrasion. Therefore some engineers claim that the present standard rattler test does not reasonably well represent the conditions in the pavement. Consequently several changes have been proposed in the method of testing paving brick.

The City of Baltimore has modified the standard rattler test by leaving out the large balls and replacing them by an equal weight of the small spheres. This change was made because it was believed that the $7\frac{1}{2}$-lb. spheres were unduly severe on brick thinner than the standard paving block. The City of Baltimore allows 3-inch brick when tested in this way a differential of $1\frac{1}{2}$ per cent over a 4-inch brick. This differential was arrived at by measuring the loss of the middle inch in a 4-inch brick, somewhat as described in paragraph 6 of § 957. This introduces a new method of testing, which is unfortunate since it makes confusion and limits comparisons. It is unfortunate that a differential for the 3-inch brick was not adopted for temporary use until the propriety of the present standard rattler-test for thinner brick could be fully investigated. Baltimore and the State Highway Departments of both New York and Pennsylvania are making comparative tests of 4-inch and 3-inch brick by this method; but at present there are insufficient data to warrant any definite conclusions.

Some competent authorities claim most of the preceding difficulties would be met and more equitable results would be obtained, if the brick were tested by the standard rattler test using the same number of bricks regardless of their size, and were then compared by their absolute loss in weight rather than by the per cent of their losses.

Attempts have been made to test paving brick by a sand blast;* but not much progress has been made.

St. Louis has discarded the rattler test, and trusts to comparing the brick on the street with standard samples previously selected.† It has not been proved that this method is not subject to more objections than the rattler test.

361. SERVICE TESTS. The relationship between the loss in the rattler and the service in the pavement has not been indisput-

* Trans. Am. Soc. Test. Mat., Vol. 16 (1914), Part II, p. 557–64; or an abstract of the same, *Engineering Record*, Vol. 70 (1914), p. 215.

† *Engineering Record*, Vol. 72 (1915), p. 200.

ably established. From time to time several experiments have been undertaken to determine the relative qualities of different grades of paving bricks by actual service in the pavement. The experiment consists in making a standard rattler test of different grades of paving blocks, and then laying short sections of pavement with each of the several kinds. For one reason or another, all of these experiments, except the one mentioned in § 962, have failed to give a conclusive result.

For example, the first of these experimental sections was laid in May, 1898, in Detroit, Michigan. Transverse strips of fourteen kinds of brick were laid in a distance of 222 feet. The blocks were tested by a former N. B. M. A. standard rattler test. A comparison between the results of the rattler tests and a general observation of the effect of three years' wear in the pavement failed to show any close agreement between the rattler test and service in the pavement. But this test was not conclusive, because it was later found the rattler test used failed to discriminate between the good and the bad brick, and it was for this reason abandoned.

962. In 1912–13 the Office of Public Roads and Rural Engineering of the U. S. Department of Agriculture directed the construction of an experimental section of road upon an extension of Connecticut Avenue known as Kensington Road, near Chevy Chase, Maryland. The improvement was 6,195 feet long, and was divided into six sections each having a different road surface. Two sections had a surface of bituminous concrete, two oil-cement concrete, one hydraulic-cement concrete, and one (the one nearest Chevy Chase) vitrified brick. The details of the design and construction of the several sections are described in the following publications: Circulars No. 98 and 99 of the Office of Public Roads; Bulletins No. 105 (1914), 257 (1915), and 407 (1916) of the U. S. Department of Agriculture. Each year an examination is made of the condition of the several sections, and a report of the same is published; and doubtless this practice will be continued for a number of years. A census of the travel on the road is taken for twenty-four hours on every thirteenth day.

The following are the particulars for the brick-paved section. The brick pavement is 18 feet wide, and 980 feet long. The concrete base is 6 inches thick, and the proportions are 1 : 3 : 7, the coarse aggegate being gravel (pebbles). The bedding course is 2 inches of sand. Fourteen varieties of paving blocks were laid. Table 55 shows the character of the blocks. The pavement

was rolled with a 5-ton tandem roller; and then the joints were filled with a 1 : 1 portland-cement grout. The depth of the bricks constituting two courses of each variety were measured, and the location of these courses were recorded, so that in the future these brick may be taken up and measured, and the amount of wear thus be determined. The average traffic one-way on half of the road during 1915 consisted chiefly of 56 horse-drawn wagons and 342 motor-driven cars.

TABLE 55

CHARACTERISTICS OF PAVING BLOCKS ON CHEVY CHASE ROAD

Ref. No.	Description of Blocks.	Absorption—Average of Five Tests.	Loss in Rattler,—Average of Three Tests.
1	Shale wire-cut lug, hard burned	1.39%	21.12%
2	" " " medium hard burned	1.31	16.36
3	Shale, re-pressed, well vitrified	0.88	25.57*
4	" " hard burned, coarsely ground	1.65	17.67
5	" " very hard burned	1.10	22.04*
6	" " coarsely ground	1.81	18.80
7	" " medium hard burned, even wear	2.29	27.92†
8	" " " " " finely ground.	3.74	22.68
9	" " " " " coarsely "	2.86	22.59†
10	Fire-clay, re-pressed, medium hard burned, coarsely ground	1.56	19.11
11	Fire-clay, repressed, soft burned, coarsely ground	2.38	37.68†
12	Shale, re-pressed, soft burned, coarsely ground	4.04	38.89†
13	Fire-clay, re-pressed, soft burned, finely ground	3.73	24.31†
14	" wire-cut lug, hard burned, laminated	3.68	31.19

* Loss due mainly to chipping. † Uniform.

Three annual inspections have been made of the above sections of brick paving and each time the conclusion is that there is no appreciable difference in wear between the several varieties of brick. Apparently time enough has not elapsed to justify any trustworthy conclusion, since the wear has been so slight as to make it impossible to discover any difference between the different varieties of brick. It has been asserted that this experiment already proves that a brick having a large loss in the rattler wears as well as one having a much smaller loss; but this conclusion is not justifiable, since the wear on any brick is as yet exceedingly small, and the difference between different varieties is too small to warrant any conclusion as to relative wear. Doubtless in due time valuable information will be obtained as to the relation between the loss in the rattler and that in actual service.

ART. 2. CONSTRUCTION

963. Fig. 176, shows the several parts of a brick pavement of the standard type.

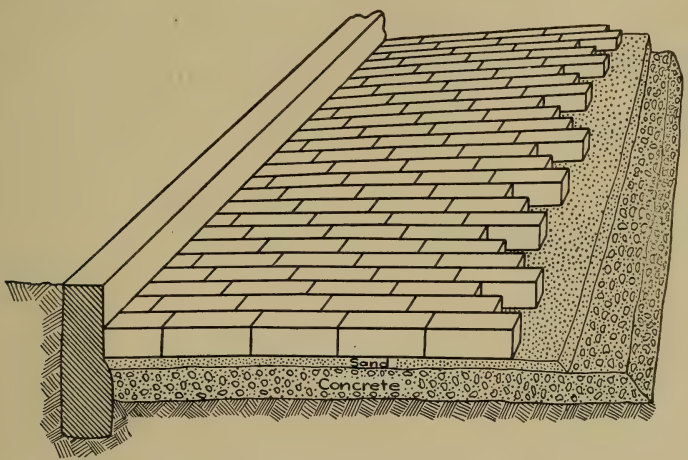


FIG. 176.—SECTION OF BRICK PAVEMENT WITH SAND CUSHION AND CONCRETE FOUNDATION

964. SUBGRADE. An essential feature in the construction of such a pavement is the proper preparation of the subgrade. It should be thoroughly underdrained, should be rolled until it is solidly compacted, and the surface should be smooth and of the correct crown and grade.

Underdrainage has been fully discussed in § 113–24; and street drainage has been considered at length in Chapter XIII. The smoothing and rolling of the subgrade is considered in Art. 1 of Chapter XV.

965. FOUNDATION. In the evolution of the brick pavement several types of foundation were used for a time.

966. Abandoned Types. The first brick pavement in this country, that at Charleston, W. Va., was laid on a foundation of 1-inch tarred boards resting on a layer of 3 or 4 inches of sand, with a $1\frac{1}{2}$-inch sand cushion between the bricks and the boards. This form was not used to any considerable extent, and has been entirely abandoned.

During the first ten or fifteen years after the introduction of brick pavements in the Middle West, the foundation consisted almost exclusively of a course of brick laid flatwise on a thin bed

of gravel or cinders. Such pavements are generally known as two-course brick pavements. The layer of cinders or gravel was leveled, and inferior paving brick were laid flatwise thereon; and then the joints of the bricks were swept full of sand. The chief defect in this form of foundation was that the joints of the lower course were not fully filled, and consequently after the pavement was in service the sand of the cushion coat (the layer between the two courses of brick) would work into these joints and permit the bricks in the wearing course to settle. To cheapen the pavement, broken and chipped brick were used in the lower course, and the tendency was to place the larger face uppermost, thus making it nearly impossible to fill entirely the joints during the time of construction. This form of foundation was abandoned on account of its cost and inferior quality.

In some localities where gravel or broken stone was cheap, brick pavements were laid upon a layer of gravel or broken stone; but the difficulty and expense of getting such a foundation thoroughly compacted and properly shaped led to the substitution of a concrete foundation.

In localities where the native soil is clean sand or fine gravel, brick pavements were constructed directly upon the natural soil. The subgrade is simply shaped and rolled. Quite a number of cities in the North, some of which have a considerable traffic, for example Cleveland, Ohio, and Galesburg, Illinois, and many cities in the South, lay such pavements on native sand. The sand is usually simply graded and puddled, the puddling being mainly to keep the subgrade hard and smooth until the bricks can be laid and the joints filled. Many southern cities lay brick pavements upon a 1-inch layer of cement mortar or fine concrete, this bedding course being used to prevent the sand subgrade from working up into the joints while the bricks are being rolled. Such foundations are wise only for light traffic streets, and the decreased cost of portland cement has led to the increasing use in such localities of a concrete foundation for even light traffic streets.

967. Old Macadam Foundation. Not infrequently a brick pavement replaces a water-bound gravel or macadam surface, in which case it may be economical to use the old pavement for a foundation for the new. For a consideration of this case, see § 791 and § 437.

968. Bituminous Concrete Foundation. For a discussion of this type of foundation, see § 792–95.

969. Concrete Foundation. At present a layer of portland-cement concrete is the almost universal foundation for brick pavements. This form of foundation is fully considered in Art. 2 of Chapter XV—Pavement Foundations.

970. Bedding Course. The bedding course is a layer of sand or mortar between the foundation and wearing coat to provide for slight variations in the surface of the foundation and small irregularities of size and form of the bricks. There are three distinct forms of bedding layer, viz.: sand, a dry mixture of sand and cement, and wet mortar.

971. Sand Bedding Course. The proper thickness of this layer will depend upon the regularity of the upper face of the concrete foundation and also upon the uniformity of the bricks in size and form.

For reasons stated later (§ 977–78), the layer of sand should be as thin as will afford a good bed for the bricks; and therefore the top of the concrete foundation should be carefully finished with a surface parallel to the surface of the pavement. Not infrequently loose fragments of stone are left on the surface of the concrete, a result which is very undesirable, since they necessitate a thicker cushion and at best prevent the bricks from coming to a uniform bearing. With good workmanship in laying the concrete, there will be no loose pieces of stone on the surface; and if they do happen to get there, they should be removed before laying the cushion coat.

The sand for the cushion should preferably be so fine as to be of a soft, velvety nature and should contain no pebbles of any considerable size, or loam, or vegetable matter. The size of pebbles permissible depends upon the thickness of the sand bed. Pebbles will prevent the brick from having a uniform bearing; the loam is likely to be washed to the bottom of the layer and cause the brick to settle; while the vegetable matter will decay or wash away, and leave the bricks unsupported. The sand should be dry when it is spread. Even a small per cent of moisture in the sand adds considerably to its volume, particularly if it is fine; and hence if the sand when laid is wet and dry in spots, the cushion will not be of uniform thickness when dry. The shrinkage of the sand cushion away from the brick causes depressions which are unsightly, unpleasant to users of the pavement, and causes the pavement to wear more rapidly. Further, the shrinkage of the sand cushion away from the brick sometimes causes an unpleasant noise when vehicles pass rapidly over these spots (§ 1055).

972. *Spreading the Sand.* The spreading of the sand should be carefully done, so as to secure a uniform thickness and to have its upper surface exactly parallel to the top of the finished pavement. After the sand has been distributed approximately to the proper thickness with a shovel, the surface should be leveled by drawing over it a template conforming exactly to the curvature of the cross section of the proposed surface of the pavement.

Fig. 177 shows a common form of template, which was used in constructing a pavement 33 feet wide. It is trussed to prevent it

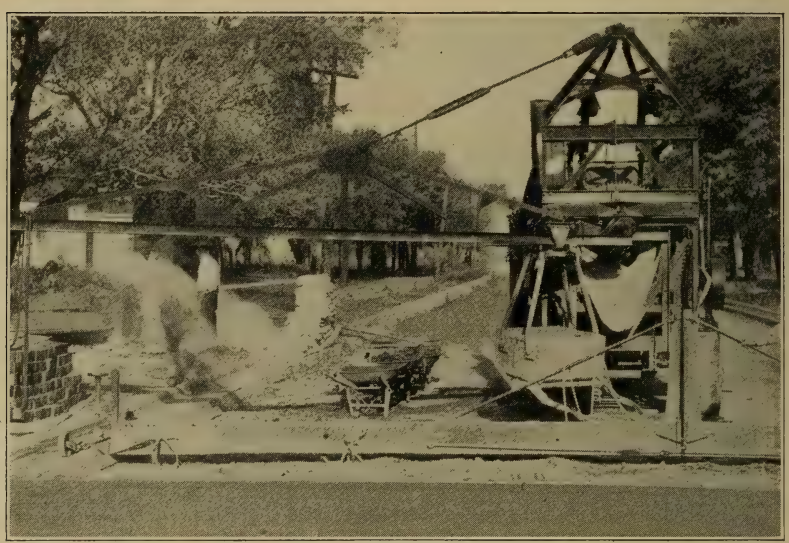


FIG. 177.—TEMPLATE FOR STRIKING THE SAND CUSHION.

from sagging at the middle; and is also trussed to prevent it from deflecting toward either the front or rear. The template is provided with two rollers at each end which run upon the top face of the concrete gutter. Some templates are provided with a roller upon a bent lever, by which the template can be lifted and rolled back. The length can be varied by means of fish-plates at each end; and the elevation of the cutting edge can be adjusted by the screw and hand-wheel at the left.

Practice differs considerably as to the length of the template. Some contractors make the template the full width of the pavement, if that is less than about 30 feet, and for a wider pavement make the template half the width of the street. This form of template must

be made of a 2-inch pine plank of sufficient width to permit of the cutting of its lower edge to the proper curvature, which may be determined by the method explained in § 718 (page 374). If the template is long, it must be braced to prevent bending and sagging; and it must have a long and substantial handle at each end by which to draw it forward, and another handle at each end by which to carry it backward. It is desirable that the template shall have considerable weight to keep it from lifting up as it is drawn forward; and when being drawn forward, the face of it should lean backward a little to keep it from lifting up. At each end there should be a roller or a metal runner to carry the template along the top of the curb or along the edge of the concrete gutter. The roller is more common, but the runner is better since it eliminates small irregularities in the top face of the forms, and also since it distributes the weight upon the forms over a longer length. If the template is to run on top of the curb, a roller also should be provided to keep it away from the curb. If the length of the template is equal to half the width of the street, one end of it may run upon a screed, or wood strip, equal in thickness to that of the cushion layer, placed in the center of the street. If there is a car track in the street, one end of the template may be made to run on the rail.

A long template requires considerable force to draw it forward, and it is difficult to move backward. Some contractors, therefore, use a template equal to one quarter of the width of the pavement. For a pavement 30 to 40 feet wide, screeds made of 2-inch by 4-inch scantlings are placed at the crown, in the gutters, and also midway between the crown and the gutter, being bedded on a thin layer of sand so that their tops conform to the finished surface of the proposed sand cushion. The position of these screeds is determined by measuring down from a string stretched from curb to curb. The template may be made of a 1-inch by 6-inch plank, with a 1-inch by 2-inch handle braced by two 1-inch by 2-inch pieces. The edge should be hollowed out to fit the curved surface of the pavement, although often this is not done. The middle ordinate for the curved cutting-edge of the template may be computed by the formula $m = \frac{C\,d^2}{D^2}$, in which m is the middle ordinate in inches, C the crown of the pavement in inches, d half the length of the template in feet and D half the width of the pavement in feet.

After the sand for the cushion layer has been distributed with shovels, the template should be drawn slowly over it several times,

any depressions that develop being filled by sprinkling sand into them with a shovel. A considerable quantity of sand should be drawn along in front of the template, as this aids materially in packing the bed. It is necessary to draw the template several times to pack the sand well, particularly if there are wet and dry spots, as the successive jarring of the sand grains causes them to settle more closely together. When the sand cushion is properly packed, it will have a uniform, smooth, velvety appearance, and will not look rough, porous, and grainy. No one should be allowed to step on the sand cushion after it has been spread, nor after it has been rolled.

Formerly, when the concrete for the base was mixed by hand, the template was pulled forward entirely by men, or sometimes by one or two horses; but now it is moved forward, at least for the first trip, by hitching it to a self-propelling concrete mixer, or better by passing a rope over a winding drum on the mixer.

973. The surface of the cushion layer is sometimes prepared with a short lute or scraper without any screeds; but the template and screeds secure a more uniform surface and also give a greater compression and a more even bed. With hand luting the surface of the pavement is almost certain to be covered with saucer-like depressions after it has been rolled. Hand luting should be prohibited except where the use of the template is impossible, as at street intersections, around manhole covers, etc.

A considerable part of the difference in tractive resistance between brick pavements No. 4 and Nos. 5 and 6 of Table 7, page 20, is due to the difference in the preparation of the sand cushion, the remainder of the difference being in the rolling of the brick (§ 991).

974. In adjusting the thickness of the sand cushion adjoining concrete gutters, manholes, etc., care should be taken that the upper surface of the brick after being rolled is not below the upper face of the gutter.

975. After the sand cushion has been struck off with the template, it should be rolled with a hand roller about 30 inches long, 24 inches in diameter, and giving a pressure of about 15 lb. per linear inch. An ordinary two-section lawn mower with a 12-foot handle is satisfactory for this work.

A 2-inch layer of sand will compress about $\frac{1}{2}$ an inch under the above rolling, and consequently the height of the template should be adjusted accordingly. To bring the template to the right height, $\frac{1}{2}$-inch strips should be laid upon the curbs and screeds; and then after striking the sand cushion and rolling it, these strips should be

removed, and the template be again drawn over the sand to test the surface of the sand bed. If the surface is high in spots, the second drawing of the template will plane them down; and if there are low spots, sand should be sprinkled over them, and the template be drawn again.

The spreading and shaping of the sand cushion is of prime importance in securing an even surface in the finished pavement; and can be successfully done only by careful and skilful men.

976. At street intersections there are no curbs or gutters to act as guides for the template, and hence the above method of striking the sand cushion can not be applied. In such cases the sand cushion is usually shaped with a hand lute. Stakes about $\frac{1}{2}$-inch square should be driven at close intervals to aid in bringing the top of the sand cushion to the right elevation.

977. *Objections to Sand Cushion.* Until comparatively recently the only bedding for the brick was a layer of sand about 2 inches thick. The purpose of the sand was to level up the foundation and to give a good bearing for the brick; and in the early history of brick pavements probably a thickness of 2 inches was required for this purpose. However, later experience proved that such a great thickness was unnecessary and also inadvisable. A better preparation of the surface of the concrete foundation, the greater uniformity in paving brick, and the closer inspection of the brick made unnecessary so thick a sand cushion.

There are three serious objections to a sand cushion.

1. With a thick cushion, it is nearly impossible to secure uniform density in the sand layer. The sand is likely to be more moist in some spots than in others; and when it dries out, it will shrink and leave the brick unsupported, which will ultimately cause a settlement of the brick and make a depression on the surface of the pavement. Such depressions are saucer-like, and can be seen in many brick pavements. Such depressions are most apparent in pavements having joints filled with cement grout, since the boundaries of the depression are indicated by a break of the bond of the joint filler. Tapping the surface of such a pavement, particularly a nearly new one, with a hammer will reveal many spots which sound hollow, showing that the sand cushion has shrunk away from the brick. Such a spot is likely to become a depression.

2. With a thick sand cushion, the rolling of the pavement is almost sure to force the sand up into the bottom of the vertical joints between the bricks, and thus prevent the cementitious joint-

filler from penetrating the full depth of the brick. Examples are on record in which the sand was thus forced nearly or quite to the top of the bricks; and not infrequently sand is forced up half the depth of the bricks, particularly if the sand of the cushion is fine, as is usually the case.

This objection to the sand cushion is particularly important if a rain should wet the cushion before the bricks are rolled; for if the sand cushion is wet, the bricks can not be rolled adequately without forcing the sand up into the joints.

3. Both of the above objections apply to any sand cushion, but particularly to a thick one; and the following objection applies to any sand cushion, even a thin one. There is danger that the sand cushion may leak away through cracks into sewers, manholes, etc., particularly if the wearing course of brick is not water-tight. Such flow of sand often occurs on steep grades. Cases have been known in which a pavement having sand-filled joints and being on a 1 per cent grade, sunk next to the curb an inch in twenty years from this cause. Even with a water-tight pavement, the sand cushion sometimes leaks into trenches opened through the pavement and left unfilled for a time. A street-railway track has a tendency to cause the sand cushion to flow away. The vibration due to passing cars has a tendency to break the bond of the joint filling near the rails and make a crack that will let water down to the sand cushion, and then the water will flow toward the curb and carry the sand with it. Further, the track will be forced down by the weight of the car and will spring back when the car has passed, thus pumping the water in and out, which forces the water through the sand cushion and tends to displace it.

4. Lately some have claimed that the sand cushion served also to give elasticity and resiliency to the pavement, and consequently protected the brick from excessive wear and possible breakage. It is likely that the sand cushion compresses under use, particularly if it is not thoroughly compacted before the brick are laid, and also if the brick are not firmly settled into the sand cushion by rolling; but under ordinary conditions this compression must be quite small, and takes place comparatively soon after the pavement is opened to travel, and hence can not have any appreciable effect upon the durability of the pavement. Further, little or none of this compression is due to the elasticity of the sand cushion, and hence the sand cushion can have little or no effect in absorbing shock. The sand cushion is a cause of shock rather than an absorber of shock.

978. In the early history of brick pavements a 2-inch cushion was customary; but later some cities reduced it to $1\frac{1}{2}$ inches, some to 1 inch, and a few to $\frac{3}{4}$ inch. At present the better practice does away with any mobile sand cushion.

979. Cement-sand Bedding Course. This form of bedding consists of a layer of dry cement and sand about $\frac{1}{2}$ inch thick. The cement and sand are thoroughly mixed dry in the proportion of 1 : 3 or 1 : 4, and then spread and struck as described for the sand cushion (§ 972–74). The mixture of cement and sand, after being spread and struck with a template, is so well compacted and of such uniform density as not to require rolling; and besides if it is rolled, even with a light roller, the bed is so hard as to make it nearly impossible to roll the brick to a smooth surface. After the bricks for the wearing coat have been set in place upon the mortar bed and rolled, the bricks should be thoroughly sprinkled, and care should be taken to see that the water really reaches all parts of the sand-cement bedding course and converts it into mortar. This can be tested by taking up an occasional brick. Subsequently the joints in the wearing course are filled with hydraulic-cement grout, as will be described later.

There are really two types of this form of construction, viz., one in which the amount of cement is sufficient to make a mortar of fair strength, and another in which the amount of cement is sufficient only to prevent the cement-sand bed from leaking away or shifting under traffic. With the latter form, the bedding course was usually 1 or $1\frac{1}{2}$ inches, and hence considerable cement was required, even though the mixture was a lean one. Gradually the bedding course was decreased in thickness and increased in richness.

980. The cement-sand bedding course has two advantages over the sand cushion: 1. It is rigid; and hence can not compress or shift under travel, nor leak away. 2. The mortar adheres to the foundation and also to the bottom of the brick, and binds them together, thus converting the foundation and wearing course into a partial monolith. Such a pavement is usually called a semi-monolithic brick pavement.

A bed of sand and cement laid as described above never makes a really good mortar. In the first place, if the water is applied sparingly there is no certainty that enough water reaches the mixture to make a mortar; and on the other hand, if water is applied profusely it may wash the cement out of the sand and destroy the mixture as a mortar. Again, even though the mixture receives the

proper amount of water, the resulting mortar will be of poor quality owing to the lack of mixing after the addition of the water.

981. Apparently the first example of this type of pavement was constructed in Baltimore, Md., in 1906; but the most noted example is the vehicle entrance to the Pennsylvania Railway Passenger Station in New York City constructed in 1910. Another innovation in this pavement was that the bricks were only $2\frac{1}{2}$ inches deep. In 1916, 7,800 vehicles passed over this pavement daily; and yet Fig. 178 shows that the surface is still practically perfect.

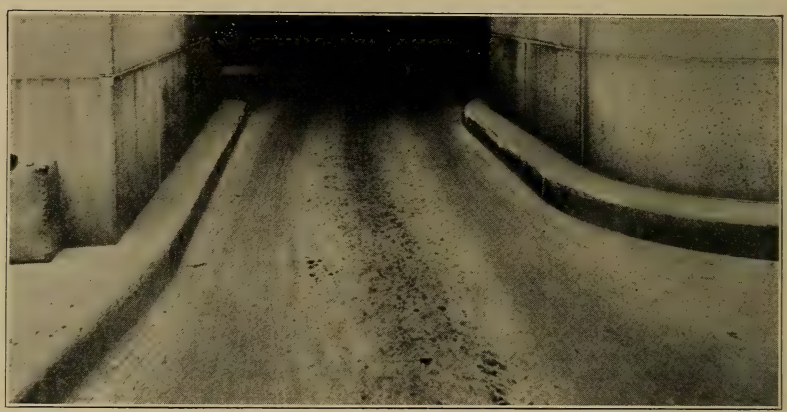


FIG. 178.—SEMI-MONOLITHIC BRICK PAVEMENT—PENNSYLVANIA PASSENGER STATION, NEW YORK CITY.

This form of construction was justly popular until the true monolithic construction was developed, as described in the next section below.

982. Mortar Bedding Course. This consists of a layer of cement mortar on which the brick are set while the mortar is still green. The chief difference between this form of construction and the cement-sand type is that the layer of mortar is placed upon the concrete foundation before it has begun to set; and then the brick are placed, rolled, and grouted before the cement in either the concrete base of the mortar bed has taken its initial set. With careful work it is reasonably certain that the whole construction is really one solid mass. This form is known as the monolithic brick pavement.

There are two slightly different forms of this type of construction. In one the concrete foundation is laid in the usual way, and on it a layer of rather dry cement mortar is spread by means of a template similar to that used in gaging the thickness of the sand cushion

(§ 972). This form was first used near Paris, Ill., in 1914. In the other form of construction the concrete foundation is laid about half an inch thicker than the depth required, and is then tamped with a tamping template (§ 462) to reduce the thickness to that specified. The tamping flushes a layer of mortar to the top; and then the surface of the concrete, or rather the mortar, is struck off with a cutting template, and the brick are set on the mortar surface. This form of construction was first used near Danville, Ill., in 1915.

When gravel is used for the coarse aggregate of the concrete foundation, the concrete and the mortar bedding course are struck off at a single operation with a double template. Fig. 179 shows this template. The front template is usually a steel I beam which

FIG. 179.—DOUBLE TEMPLATE FOR STRIKING MORTAR BEDDING COURSE.

strikes the surface of the concrete foundation; and the rear template is usually a steel channel, which is $\frac{1}{8}$ or $\frac{3}{16}$ of an inch higher than the front one, strikes the upper surface of the mortar bedding course. The space between the templates is 2 feet wide, and is kept full of mortar, which is previously mixed in a small machine mixer.

Fig. 180, page 514, shows the mortar bed after the bricks have been placed upon it and rolled. The mortar is usually forced up into the joint $\frac{1}{8}$ to $\frac{3}{8}$ of an inch. When a brick is thus removed, the surface of the mortar should be damp, but there should be no film of water on the top of the mortar. The monolithic type of construction has been adopted with great rapidity; but thus far it has been employed chiefly on rural roads.

The monolithic brick pavement is not adapted to a steep grade,

owing to the difficulty of keeping the green concrete at the correct grade and cross section.

FIG. 180.—VIEW OF MORTAR BED AFTER BRICK SURFACE HAD BEEN ROLLED.

983. Comparison of Types. For a comparison of the relative merits of brick pavements having the preceding forms of bedding course, see § 1023–33. It is not wise to attempt to discuss this phase of the subject until the complete construction of the pavement has been considered.

984. LAYING THE BRICK. Delivery. The brick are usually placed in piles at the side of the road or pavement before the grading is done. The brick should be kept clean, and should be handled so as not to needlessly nick and break them.

Formerly there was considerable discussion as to the relative merits of (1) delivering the brick along the curb a considerable time before they are to be laid, or (2) hauling them to the street as they are laid. In the former case, the brick were transported from the parking to the men who set them, either in wheelbarrows or by hand on a board or later in a pair of tongs. In the latter case, the wagon was hauled to the middle of the street on planks, and the bricks were carried by hand or with tongs directly from the wagon to the layers.

There were some disadvantages in the last method, but there was the possibility of saving $2\frac{1}{2}$ to 3 cents per square yard.

Both methods have been superseded, as far as street, i. e., wide, pavements are concerned, by an improved method of delivering brick from the parking to the setters. This device consists of a roller conveyor,—a series of rollers set in an inclined frame down which the brick roll by their own weight in a stream from the parking toward the middle of the street, and from which the setters pick them to set them into place. This is an example of one of the improvements that have helped to keep the price of street pavements down, notwithstanding the advance in cost of materials and labor (§ 637).

For rural roads, i. e., for narrow pavements, the brick are carried by hand on a pallet or in a pair of tongs from the side of the pavement to the setter.

985. It is undesirable to use wheelbarrows in transporting the bricks from the parking to the setters, since the bricks are likely to be chipped in placing them in the wheelbarrow and in dumping them out, and further since dumping them is likely to tilt the bricks already set, which will make the surface of the finished pavement uneven and rough.

986. If the brick are delivered to the setters in tongs or on a pallet, the men should be provided with planks to walk upon; and they should not be allowed to step upon the bricks before they are rolled, as it is liable to tilt them and cause the surface of the pavement to be rough after it is rolled. Further, workmen should not be permitted to track mud upon the brick. When the condition of the ground is such that mud will be tracked upon the pavement, the work of laying brick should not be allowed.

987. Direction of Courses. It is customary to lay the brick with the length perpendicular to the curb, except at street intersections; but there are a few cities in which the brick are laid in courses making an angle of 45° with the length of the street, with the idea that the tendency to form ruts would be less if the wheels crossed the bricks diagonally. There is no advantage in the diagonal over the square courses; they are more difficult to lay, cutting the corner of the brick in making the fit next to the curb is wasteful of material, and the diagonal courses do not give as good foothold to the horses.

The hill-side brick shown in Fig. 170 and 171, page 483, must be laid with its length in the direction of the street.

Occasionally a few courses of brick are laid longitudinally in the gutter, similar to the practice with stone blocks; but this is unnecessary, since the brick pavement is much smoother than the ordinary stone-block pavement, and besides the running joint where the transverse and the longitudinal sections join is likely to develop into a rut.

988. At street intersections and junctions the bricks should be laid diagonally—a compromise position between the directions of the travel on the two streets. Street intersections need special care in construction, since they are exposed to the traffic of two streets. Fig. 181 shows the usual arrangement of the courses for a street

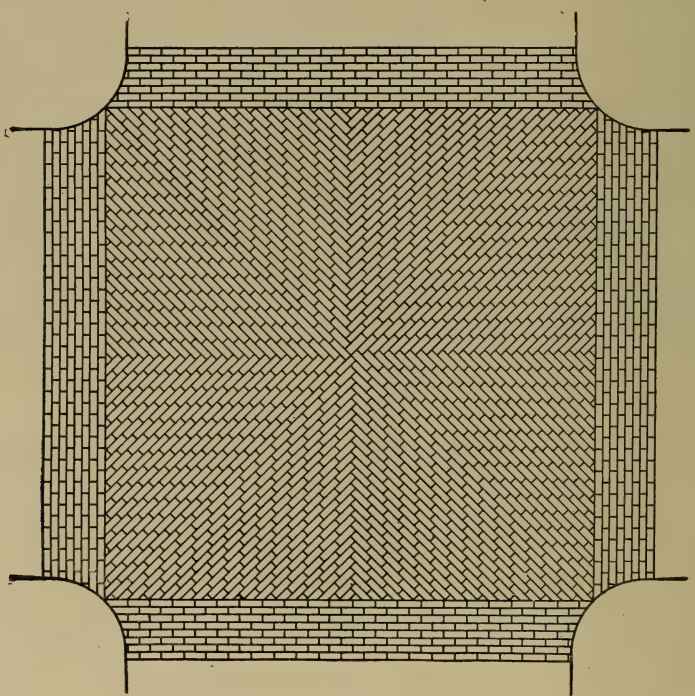


FIG. 181.—DOUBLE-DIAGONAL BRICK INTERSECTION.

intersection; and Fig. 182 and Fig. 183 (page 518) show two other arrangements that have occasionally been used. Slight objections have been urged against all three plans. The bond in Fig. 181 is weak along the middle line of each street; Fig. 182 is objectionable owing to the tendency of ruts to form along the lines running through the ends of the bricks; and Fig. 183 is defective since traffic around the corners *A* and *B* is parallel to the courses of brick.

At a street junction only half of the common area should be laid with diagonal courses. For example, assuming that in Fig. 181 the street enters the lower side of the transverse street but does not cross it, then the lower half of the intersection would be laid with courses as in the diagram, while in the upper half the length of the bricks would be perpendicular to the transverse street.

989. Setting the Brick. In setting the brick the man should stand on those already laid, and not upon the sand cushion. Under no consideration should the sand bed be disturbed. The brick should be set on edge as closely and compactly as possible, each being

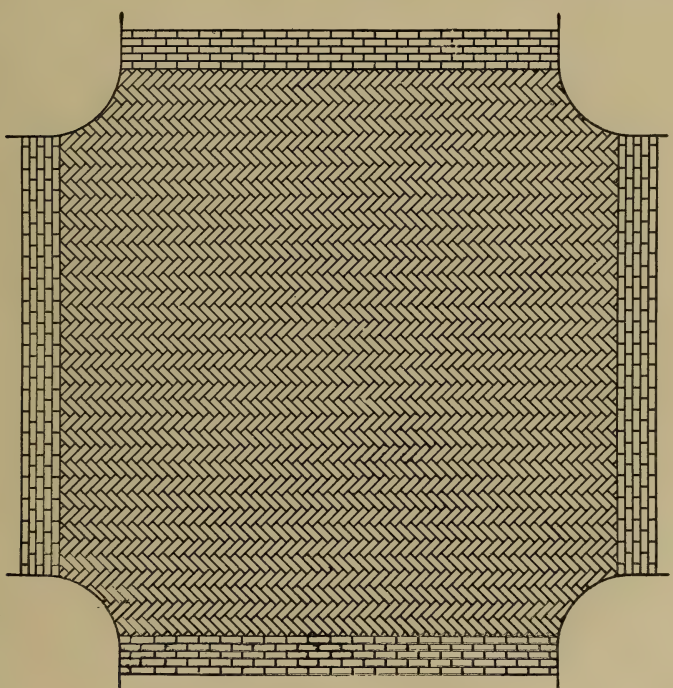


FIG. 182.—HERRING-BONE BRICK INTERSECTION.

pressed or rather bumped both endwise and sidewise against those already laid. The bricks are stronger and more durable than any material that can be used to fill the joints, and consequently the thinner the joints the better. The bond should be approximately a half brick. If the brick were laid without bond, ruts would form along the continuous end-joints; and therefore the more the bond the better. No bats should be used, except in making closures; and

in cutting a brick to close a course, care should be taken to get a square end and to make as tight a fit as practicable. As far as possible, the bats should be obtained from chipped and broken brick, or from misshapen ones rejected in the inspection after the brick are set. It is usually specified that no bat less than $2\frac{1}{2}$ inches long shall be used. Under this specification, if the space is less than $2\frac{1}{2}$ inches, it is necessary to take up the next brick and chip enough off to permit the use of a bat more than $2\frac{1}{2}$ inches. Fig. 184 shows the hammer employed in cutting, or rather in breaking, a brick to close a course.

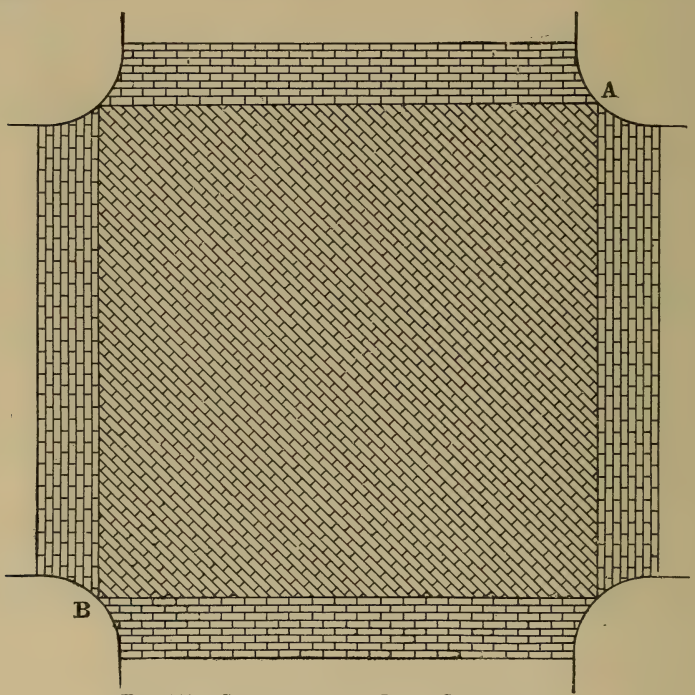


FIG. 183.—SINGLE-DIAGONAL BRICK INTERSECTION.

In some cities it is required that each four or five courses of brick shall be driven up from the face by striking with a sledge against a $2'' \times 4''$ or $4'' \times 4''$ timber resting against the last course; but this is unnecessary, if each brick when laid is pressed, or rather bumped, against the side of the course already in position. In any case the courses should be straight across the street; and if they are not laid so, they should be straightened by driving up each four or five courses from the face. Sometimes the bricks in a row are crowded

together endwise by inserting a crowbar at the curb; but this is unnecessary, provided each brick as it is laid is bumped against the end of the preceding one.

It is usually specified that nothing smaller than a $2\frac{1}{2}$-inch bat shall be used in making a closure. The alternative is either to close up the joints between the ends of the bricks by prying with a crowbar until a larger bat can be inserted, or to open up a few joints until the space at the end of the course is moderately small. The latter is undesirable, since it is likely to displace the brick vertically so as to make the surface of the pavement rough after it has been rolled.

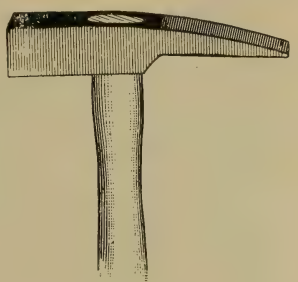


FIG. 184.—BRICK PAVER'S HAMMER.

Of course, lug brick should be set with the lugs always in the same direction.

990. Inspecting. After the bricks are laid, the pavement should be inspected, all soft, broken, and badly misshaped brick being marked for removal. To reveal the soft brick, it is customary to sprinkle the pavement heavily with a hose. While the water is being applied, the soft brick will appear comparatively dry; but after the sprinkling is stopped, the soft brick will appear to be the wetter. A brick having only a small piece chipped from the corner or edge may be turned over. Objectionable brick may be marked with chalk, a cross or circle indicating a brick to be removed and a single straight line one to be turned. Rejected brick are removed with tongs having broad flat noses and long stout handles.

991. Rolling. After all rejected brick have been removed and the pavement has been swept, it is ready for rolling. The purpose of the rolling is to settle the bricks uniformly into the bedding course. A heavy roller is undesirable, at least in the beginning of the rolling, since the first passage of it tilts the bricks to one side so much that it is nearly impossible to straighten them up again. Unless the top faces of the bricks are brought to a plane, the pavement will be rough and noisy, and will lack durability.

It is important that the rolling shall closely follow the spreading of the bedding course, so that a shower may not wet it. Whatever the material of the bedding course, if it is rained upon, the bricks with unfilled joints should be taken up and a new bedding course be spread. For much the same reason the filling of the joints (§ 994–1005) should closely follow the rolling.

If the bedding course is sand or dry sand and cement, the roller should weigh 3 to 5 tons; but if the bedding course is green mortar (§ 982), the rolling should be done with a hand roller about 30 inches in diameter, 24 inches long and weighing from 600 to 900 lb. The rolling should be continued until the surface of the pavement is smooth.

The pavement should first be rolled longitudinally, beginning at the crown and working toward the gutter, taking care that each return trip of the roller covers exactly the same area as the preceding trip so that the second passage of the roller may neutralize any careening of the brick due to the first passage. Pavements that have been rolled only once or always in one direction, are very much rougher and more noisy than when properly rolled. If a spot is skipped on the return passage of the roller, it can be detected by a casual inspection or by the noise of a passing vehicle. The first passage of the roller should be made at a slow speed to prevent undue canting of the brick. After the pavement has been rolled longitudinally, it should be rolled back and forth transversely, or at least in both directions at an angle of 45° from curb to curb. If the pavement is narrow, and particularly if it has a high crown, it may not be wise to roll it transversely or even diagonally, because of the time required and also because of the probability of breaking brick. In this case the longitudinal rolling should be more thorough.

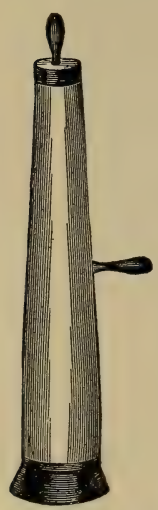


FIG. 185.—PAVER'S RAMMER.

If the rolling is well done, the sand cushion will be pushed up between the brick $\frac{1}{8}$ to $\frac{3}{8}$ of an inch.

992. There are sometimes places which can not be reached by the roller, for example around manhole covers; and in these cases the brick should be settled to place by ramming. The ramming should be done with a paver's rammer, Fig. 185, wighing not less than 50 lb. The ramming should be done on a 2-inch plank 10 to 12 inches wide and 6 feet long laid parallel to the curb. The ramming should be continued until the pavement has a good surface at the proper elevation.

993. After the rolling is completed, the joints should be inspected; and if the bedding course has been forced up between the bricks more than $\frac{1}{2}$ an inch, the bricks should be taken up and relaid.

It is usually specified that after the final rolling the surface of

the pavement shall be tested with a 10-foot straight edge laid parallel to the length of the street, and any depression exceeding $\frac{1}{4}$ of an inch shall be taken up and re-laid.

Fig. 186 shows a monolithic brick pavement after it has been rolled and before the application of the filler. The two-section hand roller used in rolling the bricks stands in the foreground.

FIG. 186.—MONOLITHIC BRICK PAVEMENT ROLLED AND READY FOR THE FILLER.

994. JOINT FILLER. The joints should be filled (1) to keep the brick in the proper position, (2) to lessen the chipping of the edges of the brick, and (3) to prevent water from penetrating to the cushion coat and to the foundation. Three forms of filler are in common use, viz.: sand, hydraulic-cement grout, and bituminous cement, i. e., asphalt or tar; and recently a mixture of tar and sand has been used.

995. Sand Filler. Sand was the first filler employed for brick pavements, and in the Middle West is even yet largely used. The sand should be fine and dry, and be worked into the joints by sweeping it over the pavement, which also should be dry. Although the sand is nominally swept into the joints, it is usually simply spread upon the surface and left to be worked in by travel, which is undesirable since the joints are then partially filled with manure and street dirt. The sand can be swept into the joints effectively and economically with a revolving machine sweeper. After the joints

have been filled, the surface of the pavement is covered with a layer of sand $\frac{1}{4}$ to $\frac{1}{2}$ inch thick, which is left on for a few weeks after the street is thrown open to travel, to secure the thorough working of the sand into every joint.

The cost of sweeping the pavement and filling the joints with sand is 0.2 to 0.3 cent per square yard, and the cost of a $\frac{1}{2}$-inch layer of sand at \$1.08 per cubic yard is 1.5 cents per square yard. To cover waste and contingencies, the sand joint-filler is usually estimated at 2 cents per square yard.

The advantages of a sand filler are: 1. It is cheap. 2. The pavement may be thrown open to traffic as soon as the bricks are laid. 3. The pavement may be taken up easily and without breakage of the brick. 4. It is practically water tight, particularly after being in service a short time. Whenever a brick pavement having a sand filler is opened, the sides of the brick are always found dry and clean a little distance below the wearing surface.

The disadvantages of a sand filler are: 1. It does not protect the edges of the brick from chipping. 2. It may wash out from the crown toward the gutter. 3. It is removed from the top of the joints by the street sweeper—either the broom or the pneumatic,—and by automobiles.

996. Cement Grout. The grout should be composed of part portland cement and 1 or $1\frac{1}{2}$ parts sand. If the sand is well graded, 1 part of cement will fill the voids of $1\frac{1}{2}$ parts of sand, and give a filler of maximum strength; but if the sand is not well graded, the grout should be 1 : 1. The cement should meet the requirements of the standard specifications. The sand should not contain more than 1 per cent by weight of clay or loam, and should contain such gradation of sizes that all will pass a 20 standard sieve and all be retained on a 100 standard sieve. Some contractors place the sand in bags when unloading it from the car, and distribute the bags of sand with an equal number of bags of cement at proper intervals along the pavement, which secures the proper proportion of ingredients and prevents loss of materials and time in measuring. The sand and cement should be mixed dry until the mass is homogeneous and of a uniform color. The cement and sand should be mixed dry so that the cement will not ball up when the water is added. For the best results a considerable amount of this mixture should be prepared at one time, but not more than will be used up in two hours.

To prepare the grout, a small batch of the mixed sand and cement, preferably not more than 2 cubic feet, should be placed in a suitable

box or machine, and water should be added to make a grout that will freely flow to the bottom of the joints without separation. It is important that the water be added slowly and that the grout be mixed thoroughly. For the best results, the dry mortar should first be reduced to a uniform and plastic mortar, and then more water should be added, while the mass is mixed vigorously, until the desired consistency is attained.

997. *Mixing Box.* The mixing may be done in a box made for the purpose, which should be $3\frac{1}{2}$ to 4 feet long, 27 to 30 inches wide, and 14 inches deep, and should have legs of different lengths, so that the mixture will readily flow to one corner of the box, which should be 8 to 10 inches above the pavement.*

The grout should be removed from the box to the pavement with a scoop shovel, and not by overturning the box upon the pavement; since by the last process the sand, cement, and water are separated, and are deposited in different portions of the pavement. While the box is being emptied, the grout should be constantly stirred to prevent a separation of the sand from the cement.

A mortar box should be provided for each 10 or 12 feet of width of pavement.

998. *Mixing Machine.* Recently a small mechanical mixer

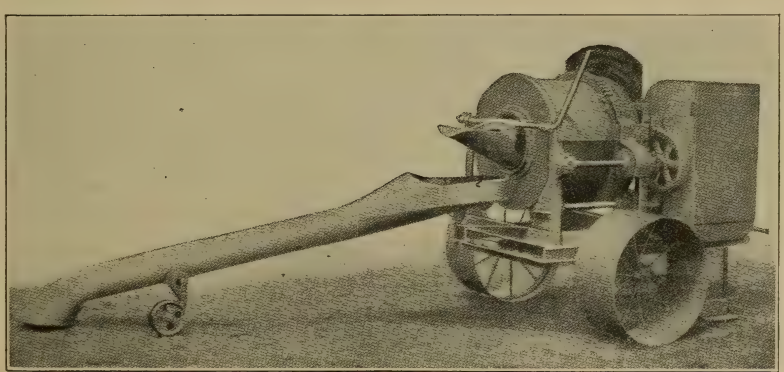


FIG. 187.—GROUT-MIXING MACHINE.

been introduced for preparing the grout. Fig. 187 and 188 show such a machine. In using the machine, it is important that

* The National Paving Brick Manufacturers Association publish complete specifications and working drawings for such a box, which may be had gratuitously of the Secretary, Cleveland, Ohio.

the mixing be not hurried; and that the conditions stated in the second paragraph of § 996 be observed.

Some engineers permit the use of the machine for mixing the first application of grout, but not for the second, as the latter should be stiffer. However, if carefully manipulated, the machine will make as good grout as can be made in a box; and besides the mixing is less likely to be slighted, and the cost of mixing is less.

FIG. 188.—GROUT-MIXING MACHINE AT WORK.

999. *Applying the Grout.* Before the grout is applied to the pavement, the brick should be thoroughly wetted by being gently sprayed. A strong stream is likely to displace the mortar. The grout should be applied to the pavement in small quantities, and should be quickly swept into the joints with an ordinary brush broom. The strokes of the broom should be mostly lengthwise of the brick to most effectively get the grout into the joints. It is better that the joints should be only about half or two thirds filled at the first application, since then there is a less depth of grout in the joints and consequently less liability of the separation of the sand, the cement, and the water.

Fig. 189 shows the process of making the first application of cement-grout filler using mixing boxes. Notice that the filler is dipped out of the box and poured upon the pavement with scoop shovel; and that the grout is spread with brush brooms.

In applying the cement filler it is very important that the grout shall not bridge across or dam up a joint; and care should be taken to see that the grout really reaches the bottom of all joints.

1000. If a grout filler is to be used with a sand cushion, the first application of filler should be made very thin, so that it will penetrate the sand that is pushed up into the joint by the rolling and convert the sand into mortar. If the sand in the bottom of the joint is not thus converted into mortar, the bricks are likely to spall on the top owing to concentrated pressure at the top of the joint, due to the expansion of the pavement.

In making this very thin grout, it is necessary first to mix the sand and cement dry, and then to add water gradually and stir the mixture vigorously, until a good stiff mortar is produced, and next to

FIG. 189.—FIRST APPLICATION OF GROUT FILLER.

continue the gradual addition of water and the mixing until a very thin mortar results. If all the water is added at once, or if the water is added too rapidly, or the mortar is not thoroughly and continuously mixed while the water is being added, it is nearly impossible to keep the sand, cement and water from segregating.

1001. After the first application has been carried forward 40 or 50 feet, and after it has settled but before the initial set has begun, a second application should be made in the same manner as the first, except that the grout should be somewhat thicker.

Fig. 190 shows the process of making the second application of grout filler, when the mixing bases are used. The grout is dipped

with a scoop shovel and spread with a squeegee, a wooden scraper having a rubber edge.

1002. After the second application has settled but before initial set has begun, all surplus grout on the surface should be forced along

FIG. 190.—SECOND APPLICATION OF GROUT FILLER.

over the pavement with a squeegee. The squeegee should always move at an angle with the joints, thus leaving them level full.

In making the final finish, the squeegee should be drawn, not pushed, over the surface; or in other words, the workmen should not track up the finished surface, for doing so raises little projections on the surface of the grout which when hardened are very destructive upon automobile tires. This precaution was not observed in building the automobile brick race-track at Indianapolis, even though recommended by the engineer; but after the track was completed, it was necessary to spend considerable time and money to remove these projections. Of course, on a public highway these projections will ultimately be worn off by steel-tired vehicles; but in the meantime much damage will be done to auto tires, and it costs practically nothing to prevent the projections.

Fig. 191 shows a vertical view of a perfectly grouted brick pavement. Fig. 192 shows a well-grouted Ohio rural brick road.

Fig. 193 shows a sand-cushion cement-grouted brick pavement on South Sixth Street, Terre Haute, Indiana, when 28 years old. This is one of the first, if not the first, cement-grouted brick pave-

ment; and it is in a remarkably good condition. The view was taken two blocks from the main business street. When this pave-

FIG. 191.—VERTICAL VIEW OF A PERFECTLY GROUTED BRICK PAVEMENT.

ment was laid Terre Haute had a population of 30,217, and in 1910 it had 58,157. The joint filler and the brick have worn down together, and the surface is as smooth as a marble mosaic. The top

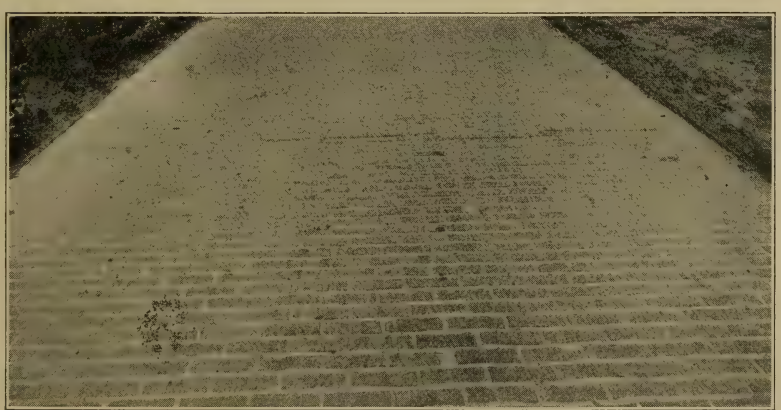


FIG. 192.—A WELL-GROUTED OHIO RURAL ROAD.

faces of the brick are flat, and the joints are level full of cement grout. Scarcely a single chipped or broken brick can be found; and the

general wear, in the middle third of the street, has been only about $\frac{1}{32}$ to $\frac{1}{16}$ of an inch of depth, with a very few holes $\frac{1}{8}$ inch deep caused by soft brick. The brick are not as good as those made at the present time; but the pavement, particularly for that time, was unusually well constructed. It was provided with an adequate foundation,

FIG. 193.—SAND-CUSHION CEMENT-GROUTED BRICK PAVEMENT 28 YEARS OLD.

the brick were well burned, and were carefully and thoroughly rolled, and the joints were entirely filled with good portland-cement grout, and consequently this pavement has worn exceedingly well. Of course other pavements constructed with as good material and with the same care would wear equally well.

1003. With hill-side brick (§ 936) the grout should be swept from the grooves before it sets.

1004. After the joints have thus been filled, and after the grout has set so that a coating of sand or earth will not absorb moisture from the joint filler, a half inch of fine sand should be spread over the entire surface of the pavement; and if the weather is very hot or dry, the sand should be sprinkled at intervals for two or three days, to insure that the cement does not lose by vaporization the water necessary for chemical combination in setting. Some engineers prefer hay or straw instead of sand or loam, since they can be moved ahead and used a second time.

Travel should be kept off the pavement from seven to ten days, or at least until the cement has fully set, and it is much better if

travel is kept off longer. Some engineers specify three weeks in warm weather, and longer for cold weather. If the cement filler is disturbed before it is firmly set, it is practically no better than sand. If the cement filler is put in as described above and allowed to set firmly before travel is admitted, the filler will wear no faster than the best paving blocks and will prevent spalling and chipping of the bricks at the edges and corners.

1005. To separate the grouted section from the ungrouted portion, a row of metal strips $\frac{1}{16}$ by 6 by 36 inches should be inserted in a transverse joint of the pavement. By this means the grouting will end in a transverse joint. These metal strips should be removed when the grout has become stiff, but before initial set.

1006. *Cost.* The amount of grout required will vary with the openness of the joints, and also with the quantity of sand of the cushion course that works up into the lower part of the joints while the bricks are being rolled.

"If a 1 : 1 portland-cement grout is used, the area filled with one barrel of cement will be as follows: With 4-inch brick and a sand cushion, 32 square yards of re-pressed brick, and 24 square yards of wire-cut lug brick; and with 4-inch brick on a $\frac{3}{8}$-inch mortar bed, 30 square yards of re-pressed brick, and 22 square yards of wire-cut lug brick."* It is quite common to estimate $\frac{3}{8}$ of a barrel of cement per square yard for 1 : 1 grout. Of course, the cost of the cement for the filler will vary with the market price of cement. The grout will require about 0.2 cubic foot of sand per square yard of pavement; and its cost at $1.00 per cubic yard, will be about 0.7 cent per square yard of pavement. The cost of applying the grout filter will vary considerably with the details of doing the work, i. e., the number of applications, and whether the mixing is done in a box or a machine; but the cost will usually be 2 or 3 cents per square yard. The total cost of grout filler was formerly 8 to 10 cents per square yard, but in 1917 was usually 10 to 12 cents per square yard.

1007. *Merits.* The advantage of the cement filler is that it protects the edges of the bricks from chipping, and thus adds to the durability of the pavement. When the joints are filled with sand, the edges of the brick chip off, the upper faces wear round, the pavement becomes rough, and the impact of the wheels in jolting over the surface tends to destroy the brick; while with a good cement filler, the edges do not chip, the whole surface of the pavement is a smooth

* H. E. Bilger, Road Engineer, Illinois Highway Commission, in *Engineering and Contracting*, Vol. 46 (1916), p. 502.

mosaic over which the wheels roll without jolt or jar, and consequently the life of the pavement is materially increased. Fig. 193, page 528, shows a grout-filled pavement 28 years old upon which there have been practically no repairs. See the last paragraph of § 1002 for a description of its present condition.

An objection to the cement filler is that it does not take up the expansion of the pavement due to increase of temperature, and that consequently the pavement is likely to rise from the foundation and give out a rumbling noise as vehicles go over it. This rumbling can be eliminated by inserting longitudinal expansion joints as described in § 1017.

Another objection to the cement filler is that in making repairs it is difficult to remove the bricks without breaking many, and it is difficult to clean the bricks so that they may be used again. This is an advantage, if it will in any degree prevent the tearing up of the pavement; and at best this objection ought not to have much weight against durable construction.

A third objection is that the street can not be used while the cement is setting. Often the cement is not allowed to set fully before throwing the street open to travel, and consequently the chief advantage of the rigid filler is lost. The semi-monolithic and the monolithic types of construction are free from this objection (§ 979 and § 982).

1008. Bituminous Filler. Both asphalt and tar are used as a filler for the joints of a brick pavement.

1009. *Asphalt Filler.* The various producers and refiners of asphalt prepare a grade of asphalt particularly for use as a filler for brick, stone-block, and wood-block pavements. For the specifications of such, see § 544.

1010. *Tar Filler.* For the specifications of a tar suitable for a joint filler for brick pavements, see § 576–77.

1011. *Applying Bituminous Filler.* The bricks should be dry, and the bituminous filler should be hot enough to flow freely and adhere to the brick. The asphalt fillers should be applied at a temperature of 350 to 450° F., and the tar fillers between 300 and 350° F. If either filler must be heated hotter than this to make it pour freely, then it will be so hard as to chip out of the joint in cold weather; and if it can be poured much colder than this, it will be so soft as to run out of the joints in hot weather. However, manufacturers vary the temperature of pouring to fit extreme climates.

The bituminous filler is poured into the joints through the point

of a cone-shaped pouring can. The point of the can has a cast iron tip with an opening in it about $\frac{1}{4}$ inch in diameter. The tip is opened and closed by a valve, which is operated by a handle projecting at the top of the can. The cast iron tip is placed in a joint, the valve is opened, and the can is drawn along as the joint becomes filled. A helper fills the can as it is emptied.

As soon as the joints in a short section of the pavement have been filled, and while the bituminous cement is still soft, a light layer of sand should be spread over the pavement, but only enough to prevent the cement from sticking to passing wheels. In cold weather the sand should be heated so as to bond readily with the pitch.

Particular care should be taken in applying the filler around manholes, at the gutter, etc., to prevent leakage of water into the subgrade.

1012. A pouring can, or rather tank, having multiple spouts has recently been put upon the market. The tank is mounted upon wheels, and somewhat flexible spouts project below. The tips of the spouts are placed in the joints, and the tank is drawn along by hand as the joints are filled.

Contractors claim that it is materially more difficult to fill the joints of a pavement made of wire-cut lugs than of re-pressed brick, as with the former it is more difficult to keep the tip of the pouring can in the joint. Recently bituminous filler has been successfully applied with a squeegee. The only objection to this method is that the cement may be chilled by contact with the brick and fail to penetrate to the full depth of the joint.

1013. *Cost.* The cost depends upon the locality, the closeness of the joints, and the amount of bituminous material left upon the surface of the pavement. A tar filler usually costs 8 to 10 cents per gallon and asphalt about 10 to 12; and 1 to $1\frac{1}{4}$ gallons is generally required for a square yard of pavement. The labor of heating and pouring is usually about 5 to 7 cents per square yard. The total cost of a tar filler is therefore about 13 to 15 cents per square yard, and of asphalt about 15 to 19 cents.

1014. *Merits and Defects.* A bituminous filler is superior to sand in that it makes a perfectly water-tight pavement, and better protects the edges of the bricks. Bituminous filler is preferable to cement grout in that the pavement can be opened to travel as soon as it is laid; but bituminous filler does not protect the edges of the brick as well as grout.

1015. Tar-sand Filler. Recently a mixture of tar and sand, usually called tar mastic or pitch mastic, has been employed as a joint filler for brick pavements. The tar pitch should conform to the specifications in § 576–77. The filler is made of pitch and as much fine clean sand as the pitch tar will carry, usually about 1 : 1; but in no case should the volume of the sand exceed that of the tar. The coarser the sand, the smaller the proportion of it should be used. The sand when mixed with the tar should be at a temperature between 300° and 400° F.; and the tar shall be heated to 250° to 325°. The mixing is most easily done with a hoe in a wheelbarrow or a concrete buggy. The mastic is poured on the pavement and pushed into the joints with a squeegee.

Fig. 194 shows the method of applying tar-mastic filler. The smoke indicates that the sand was too hot.

This filler has been used for brick pavements in a few cases with every evidence of success; but the experience is too limited in both

FIG. 194.—APPLYING TAR-SAND FILLER.

extent and time to establish the merits of the method. A tar-sand filler protects the edges of the bricks better and is less susceptible to temperature changes than tar alone; and the only question is

whether or not the tar-sand filler can be made so as to flow satisfactorily into the joints of a brick pavement. Since the joints of stone-block pavements (Chapter XVIII) are wider than those of brick pavements, such a filler is more needed and can be more satisfactorily applied to the former than to the latter. For specifications for a tar-sand filler, and for further details concerning its use, see § 110.

1016. EXPANSION JOINTS. Expansion joints may be either longitudinal or transverse.

1017. Longitudinal Joints. With a sand filler (§ 995) there is little or no need for expansion joints, since the sand in the joints will yield enough to compensate for the expansion or contraction due to changes of temperature. For much the same reason, expansion joints are not necessary with a bituminous filler (§ 1008). But with a rigid grout filler and sand bedding-course, it is necessary to construct longitudinal expansion joints next to the curb or gutter on each side, to provide for the expansion and contraction due to changes of temperature in the wearing course. To be perfectly safe the expansion joint should extend to the bottom of the concrete base; although often it reaches only to the top of the concrete base. The omission of longitudinal expansion joints is likely to cause the expansion of the wearing course to lift the brick from the bedding course and to cause the pavement to give out a deafening noise when a heavy-laden steel-tired vehicle goes over it at any considerable speed (§ 1027).

The longitudinal expansion joint may be made by placing a $\frac{1}{2}$- to 1-inch board on edge against the curbs; and then after the bricks are set withdraw the plank and fill the space with tar or asphalt. A close examination of Fig. 171, page 483, will show such a plank in position with wedges between it and the curb to facilitate the removal of the board. An objection to the poured expansion joint is that it is liable to get blocked by a pebble or a brick spall getting into the space before the bituminous material is poured. Instead of using the plank as described above, a much better way is to place pre-moulded strips of mastic next to the curbs before laying the brick. There are several forms of these strips on the market. The strips are usually $\frac{3}{4}$ of an inch thick for a pavement 20 to 30 feet wide, and proportionally thicker for wider pavements. The strips are comparatively short, and should fit closely end to end; and should extend the full depth of the brick, and should be stiff enough to stand alone in place until the bricks are placed against

them. The material should be pliable at 32° F., and should not melt or flow at 125° F.

A true monolithic pavement needs no longitudinal expansion joints, although they are sometimes provided.

1018. Transverse Joints. Transverse expansion joints are not needed with either a sand or a bituminous filler. Opinions differ as to the need of such joints with grout filler; but the best practice seems to be to omit them.

There are two forms of transverse expansion joints in use. In one method two or three or four of the transverse joints between the courses of brick are filled with bituminous cement. In the other method a ½-inch plank is inserted between courses of brick at intervals of 25 to 50 feet; and then after the brick are laid and grouted, the plank is removed and the space is filled with bituminous cement. Or, instead of the plank, a pre-moulded sheet of mastic (§ 1017) is used.

1019. There are several objections to transverse contraction joints in a pavement having a grout filler.

1. The expansion joint is weaker than other joints, and hence the weight of passing wheels is likely to break the bond of a brick next to the joint, and then the bond of one brick after another fails in succession.

2. The contraction joint concentrates all of the shortening of a section of the pavement at one line, and opens the contraction joint so as to permit water to enter the sand cushion. The water acts as a lubricant and causes the sand to shift, and often permits a brick to settle; and then the impact of a passing wheel breaks the bond of another brick, and the defect gradually extends. The water may freeze and lift the pavement, which rarely returns to its former position, for the same reason that the continued action of frost lifts loose stones to the top of the ground. If there are no contraction joints, the contraction is likely to open many narrow cracks which are less harmful than a few wider ones.

3. The filler in the expansion joint becomes more rigid at the top than at the bottom, partly by vaporization and oxidation, and partly by the pounding in of street dirt; and consequently the expansion of the pavement concentrates pressure at the top of the joint, and the adjoining brick are spalled. This roughens the pavement and increases the effect of impact, which breaks the bond and causes the sand cushion to shift. If there are no transverse expansion joints, the expansion simply produces compression in the pave-

ment and does no harm. This conclusion is in harmony with experience with concrete pavements (§ 466–68), namely, that transverse expansion joints are not only not needed, but are a positive detriment.

1020. Fig. 195 shows two examples of failures due primarily to a contraction joint. In the left-hand view the wheel-track crosses the joint near the middle of the picture; and doubtless the damage

FIG. 195.—FAILURES AT TRANSVERSE CONTRACTION JOINTS.

started at this point and gradually progressed in all directions, for each of the three reasons explained in § 1019. In the right-hand view the contraction joint slopes up and to the right across the picture. For some reason the damage is more to the right of the joint than to the left, perhaps because of defective grouting (§ 1059).

1021. Expansion Joints at Anchors. An expansion joint $\frac{1}{2}$ to $\frac{3}{4}$ of an inch wide should be provided around manhole covers, water boxes, etc., which might act as anchors to prevent the expansion of the pavement. Frequent examples are seen where the pavement buckles at such points owing to the lack of adequate provision for expansion.

1022. HEADERS. A header is a wood or stone or concrete curb or protection placed at the end of the pavement or at an alley and street intersection, to protect the edge of the pavement from vehicle wheels bumping against it in getting on the pavement. A wood plank 2 to 4 inches thick, held in position by posts, is sometimes used; but stone or concrete are more durable, and are not much higher in first cost. A 4-inch hard limestone or a 6-inch concrete slab is usual.

With a monolithic brick pavement the header is not absolutely necessary, as the brick will stand a good deal of bumping without being dislodged; but even in this case the use of a substantial header is true economy.

1023. Comparison of Types of Brick Pavements. Brick pavements differ chiefly as to the nature of the bedding course and the character of the joint filler. The different types will be compared as to durability, smoothness, noisiness, thickness, time in construction, and cost.

1024. Durability. The durability depends chiefly upon the material of the joint filler. The merits of the several joint fillers have already been considered; and hence little need be said here. However, it may be repeated that a cement-grout filler protects the edges of the brick best, and that such a filler makes the most durable pavement.

1025. Smoothness. It has been abundantly proved by experience in the field that it is easier to get a smooth surface with a mortar bedding-course than with a sand cushion. Smoothness promotes durability; and besides the smoother the pavement the less noisy it is.

1026. A grout or a bituminous filler is not retained in the joints of re-pressed brick as well as of those not re-pressed, since the former have a rounded edge while the latter have a square edge. With a rounded edge, if the joint is filled level full, the filler feathers out at its edges and is easily crumbled off; and then the next wheel drops into the depression, and breaks out more of the filler. Soon the filler is broken out to a considerable depth, and then the joint becomes a groove into which each passing wheel drops with a bump that disintegrates the edge of the brick. With a square-edged brick the joint filler wears away only as fast as the face of the brick.

1027. Noisiness. A brick pavement may produce noise from two causes. One of these is the roughness of the surface, which has just been considered in the preceding paragraph.

The second occurs only with a sand bedding-course and grout-filled joints, and is due to the fact that the wearing course is separated from the bedding course, which causes the pavement to give out a rumbling or roar when a steel-tired wheel goes over it. This separation may be due to the drying out of the sand cushion in spots, which causes it to shrink away from the brick wearing coat. Many brick pavements rumble from this cause. When this occurs the pavement gives out a rumbling when a steel-tired wheel goes over

one of these hollow spots. Sometimes a high temperature lifts the whole wearing coat up from the bedding course, when the noise is very marked. Something like the same result occurs in cold weather, possibly owing to the expansive action of freezing water in the soil behind the curb crowding the curbs inward and thus lifting the wearing coat up from the bedding course. If each curb of a 40-foot pavement is forced inward $\frac{1}{50}$ of an inch, the crown of the pavement will be lifted from the foundation more than an inch. This result will occur only when the subsoil outside of the curbs freezes while it is at least nearly saturated with water.

Both the semi-monolithic and the monolithic types of brick pavement are free from any rumbling noise.

1028. Thickness. Nominally there are three forms of bedding courses; but really there are only two, viz.: sand, and cement mortar. A brick pavement has thickness primarily to enable it to distribute the concentrated load of a wheel over sufficient area of the subgrade to enable the native soil to support the load. The pavement distributes the load mainly, if not wholly, by its strength as a beam, which enables it to bridge over any soft spot and also to resist the lifting action of frost in the subgrade.

The thickness of a brick pavement having a sand cushion is about as follows: foundation, 6 inches; sand cushion, 2 inches; and wearing coat, 4 inches,—a total of 12 inches; but considered as a beam, the effective thickness of such a pavement is only that of the concrete base, i. e., 6 inches. The thickness of a pavement having a cement mortar bedding-course is as follows: foundation, 6 inches; bedding course, 1 inch, and wearing coat, 4 inches,—a total of 11 inches; but considered as a beam, the effective thickness of such a pavement is 11 inches. The strength of a beam varies as the square of its depth, and therefore the relative beam strength of the two pavements as above is as 36 to 121; or the monolithic pavement considered as a beam is 3.35 times the stronger.* Even though there may not be a perfect union between the foundation and the wearing coat, the above ratio is nearly correct, for the bedding course is nearly at the center of the beam and hence there is little or no longitudinal shear upon it, and hence the pavement acts nearly as a solid beam. Laboratory experiments show that a well-grouted layer of brick has as great transverse strength as a concrete slab of equal depth.

* For data on the strength of slabs of monolithic brick pavements, see *Engineering Record*, Vol. 73 (1916), p. 86; and *Engineering News-Record*, Vol. 79 (1917), p. 820–23.

Since the practicability of laying the brick in a bed of cement mortar has been demonstrated, it has often been proposed to reduce the total depth of a brick pavement having a mortar bedding-course and cement-filled joints. In support of the possibility of making thinner pavements when the wearing coat is cement-grouted, it is often cited that 4-inch concrete roads in California give at least fair satisfaction; and that many, perhaps most, concrete roads in the Mississippi Valley are only 6 inches thick. Some engineers have reduced the thickness of the concrete foundation, and others have reduced the thickness of the wearing coat.

The extreme of the former practice is perhaps in Stockton Township, Vermilion County, Illinois, in which in 1916 6½ miles of rural brick roads were constructed with a brick wearing coat 4 inches thick and a concrete base only 1 inch thick. Another striking example is in Polo, Illinois, where in 1917 4-inch bricks were laid on 2 inches of concrete. The purpose of either the 1-inch or 2-inch concrete in the above examples is not to act as a foundation to support either the brick or the load upon the pavement, but to make a smooth surface on which to set the brick and also to prevent the grout filler from penetrating the subgrade. In both of the above examples the subsoil is clay or loam.

An example of the practice of reducing the depth of the brick is to be found in many cities in the Mississippi Valley west of the river, in which many pavements were built between 1912 and 1917 using vertical-fiber brick 2½ inches deep. Another example of the use of 2½-inch brick is the driveway entrance to the Pennsylvania Passenger Station in New York City (§ 981). The wear on a grout-filled brick pavement is very small (see Fig. 193, page 528); and hence a brick 2½ inches deep will last nearly as long as a brick 4 inches deep.

An example of reducing the thickness of both the foundation and the wearing coat, is over 50 miles of rural brick roads in Florida consisting of 3½-inch grouted brick laid on puddled native sand; and similar pavements are laid on the streets of several southern cities. Some of these pavements have been in service two years, and have carried 10-ton motor trucks without any signs of distress. Of course, these pavements are not subjected to frost action.

1029. It is impossible to compute or otherwise determine in general the permissible minimum thickness for any particular form of construction, since the required thickness varies greatly with the character of the subsoil and the climate; but it is certain that under conditions where a sand-cushion brick pavement gave fairly satis-

factory service, a thinner pavement may be used if it is built monolithic. Only considerable experience will determine the safe and not extravagant thickness of a pavement.

1030. Of course, the cost will vary with the thickness; and whether it is cheaper to diminish the thickness of the concrete base or that of the brick-wearing course will depend upon conditions. There are localities where it is economical to decrease the depth of the brick, as for example where bricks are expensive and materials for concrete are cheap; and on the other hand, there may be conditions under which it is wiser to decrease the thickness of the concrete.

1031. Time under Construction. One of the most important advantages of the monolithic type of brick pavement is the length of time required for construction. All parts of it (the concrete foundation, the bedding course, and the grout filler) are constructed and seasoned simultaneously. With a concrete foundation, sand cushion, and grout-filled joints, the concrete foundation should be allowed to set for about 20 days before the sand cushion is spread and the brick set (see § 464); and another 20 days should be allowed for the cement grout to harden. This is one reason why a grout filler is not used more frequently.

1032. Cost. The cost of construction of the monolithic type is 10 to 12 cents per square yard less than that of the sand-cushion grout-filled type. The reasons for this difference of cost is as follows: 1. All parts of the work are done at substantially the same time, and hence so much care is not required in protecting and caring for the work while the cement sets. 2. A lighter roller is used in rolling the brick. 3. Less sand is used for the bedding course. 4. There is less risk of having to take up and re-lay brick on account of the sand cushion having been rained on. 5. It is possible to use either a thinner concrete foundation or a shallower brick. 6. For a rural road the monolithic construction does away with the need of a curb or edging.

1033. Conclusion. In all points the monolithic pavement is superior to any other type of brick pavement.

1034. Pavement Adjacent to Track. It is exceedingly difficult to construct any pavement adjacent to a street-railway track that will not need frequent and extensive repairs. A large part of the difficulty is due to the foundation of the track, which subject has been considered in Art. 3, of Chapter XV—Foundations for Street-railway Tracks. Another difficulty is in keeping a water-

tight joint between the head of the rail and the pavement. Fig. 196 shows the standard practice of laying brick in the track area when

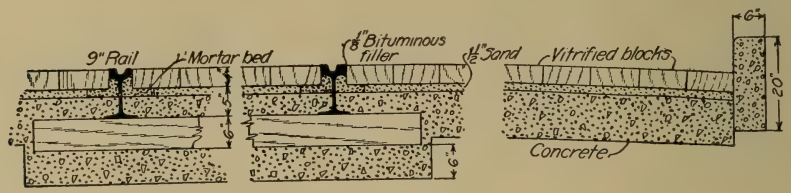


FIG. 196.—STANDARD PRACTICE IN BALTIMORE, MD.

a grooved rail is used; and Fig. 197 shows the corresponding arrangement when a T rail is used. Most brick manufacturers

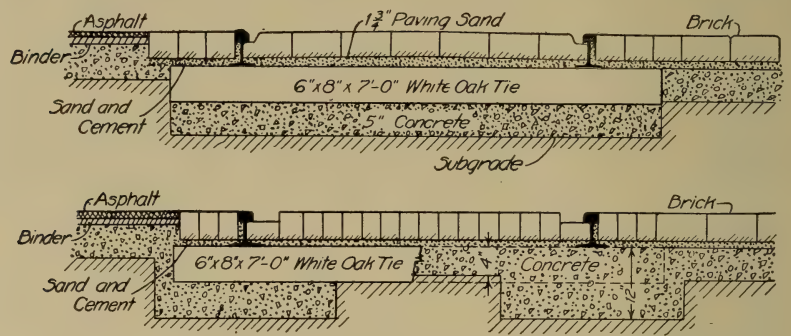


FIG. 197.—STANDARD PRACTICE OF FORT WAYNE AND WABASH VALLEY TRACTION CO.

make the "bull-nose" brick for placing next to the inside of the rail as shown in the upper view in Fig. 197. Notice in the lower part of Fig. 197 that the paving between the rails is level with the top of the rails; but often it is made level a little below the top of the rail. Notice also that the lower half of Fig. 197 has a longitudinal concrete beam under each rail.

Bricks are much used for paving the railway area, particularly between the rails, because of their low first cost and of the ease with which they can be laid.

It is practically impossible to maintain a brick pavement with a sand cushion adjoining a railway track, since the cushion will shift under travel and since water will leak into the cushion and freeze.

1035. MAXIMUM PERMISSIBLE GRADE. The Committee of the American Society of Civil Engineers recommends 12 per cent as the permissible maximum grade for a brick pavement with a

bituminous filler, and 6 per cent for a grout filler—see Table 15, page 58. The report impliedly recommends the use of a plain brick and bituminous filler on steep grades; but this is not in accordance with accepted good practice. The best practice employs grout on all grades; and uses plain brick on grades up to 5 or 6 per cent, and hill-side brick (§ 936) for grades up to 10 or 12 per cent. Hill-side brick and grout filler have given fair satisfaction on grades as high as 15 and 18 per cent.

1036. Streets Paved with Brick. The preceding discussion of brick pavements has been without special reference to either city streets or country roads. A few differences resulting from the different locations of the pavement remain to be considered.

The chief difference in the construction of a brick pavement on a city street and on a rural road is due to the fact that usually the paved portion is wider on the former than the latter. This necessitates either the use of a longer template in striking the concrete foundation and the bedding course, or the placing of screeds and the use of a shorter template. The construction of the concrete foundation has been discussed in Chapters VII and XIV. The template employed in striking the concrete is described in § 460, and that used for the bedding course in § 972.*

The bricks are usually transported from the parking to the setter either by hand with pallets or tongs, or by a roller gravity conveyor —usually the latter.

Longitudinal expansion joints are always required for street pavements.

1037. Roads Paved with Brick. The foundation for brick pavements on rural roads more frequently than on city streets is an old macadam road (§ 437).

Formerly brick roads usually had a sand cushion, but recently the semi-monolithic or monolithic construction is ordinarily employed—generally the latter. Fig. 198 shows two typical views of the construction of a monolithic brick road. The left-hand view shows the bricks, the fine and coarse aggregate, and the cement delivered ready for work, and also the side forms in place. Notice that the materials have been transported to the job on an industrial railway. The right-hand view shows work in progress. In the latter notice the steel side-forms, and the tamping template. The double template (§ 982) is shown between the tamping template

* For an illustrated account of the laying of a monolithic brick pavement 33 feet wide on a city street, see *Engineering News*, Vol. 76 (1916), p. 978–79.

and the concrete mixer, and is weighted down with bags of cement.

Formerly the sand-cushion brick road was built with an independent curb (§ 729–34), or with an integral curb or an edging (§ 771). Fig. 199 shows the concrete foundation for a sand-cushion

FIG. 198.—CONSTRUCTION OF MONOLITHIC BRICK ROAD.

FIG. 199.—CONCRETE FOUNDATION WITH EDGING.

brick road with edging, in process of construction. The concrete is being spread to grade with shovels and smoothed with the back of a shovel. The surface on the concrete slab is not first-class; but is good for the method used, and is good enough in consideration that a sand cushion is later to be used. The combined curb and gutter

(of the shallow V type) is completed on the far side, and the form for the integral edging is in position in the foreground of the left side. The trussed scantling or template is being used in testing the crown or elevation of the concrete, the ends of the projecting strip indicating the height the concrete should have.

Fig. 200 shows four views of a semi-monolithic brick road with edging, in process of construction. In view 1, notice the low spot in the sand-cement bed. In view 2, notice that the men are walking on the ungrouted brick, which is objectionable, but less so with a cement-sand bed than with a sand-cushion (§ 971). In

1. Striking the Sand-cement Bed. 2. Laying the Bricks.

3. Sprinkling the Brick. 4. Second Application of Grout.

FIG. 200.—CONSTRUCTION OF MONOLITHIC BRICK ROAD WITH EDGING.

view 3, the stream of water is so solid or heavy as to wash out the cement in the bedding layer, although the laborer says the stream does no harm as he always plays upon the center of a brick. View 4 shows the mush-like consistency of the last coat of grout, which is dangerously near being too thick to run into the joints well.

1038. Since the introduction of the monolithic brick pavement, the brick wearing-coat for rural roads is laid without any curb or edging (§ 471), experience having shown that the bricks at the edge of the pavement are not dislodged by traffic.

The edge or corner of a monolithic brick road is rather rough and ragged, and very destructive of automobile tires in turning off and onto the pavement, if the earth is not kept well filled up against the pavement. It is nearly impossible to keep the earth shoulders full, and gravel or broken-stone shoulders are seldom used; and hence this ragged edge is an objection to omitting the concrete edging. This objection could be eliminated by laying a bull-nose brick (see § 1034) at the end of a course; but it is not known that this has ever been done. The outer corner of the concrete edging can be readily rounded off with an edging tool, although it is not often so done.

1039. Cost of Brick Pavements. The cost will vary with the locality and the details of construction, and consequently any general statement of cost will be only approximately true for any particular case.

The grading is usually done by the cubic yard; and the cost varies with the character of the soil, the depth to be removed, the length of haul, etc. The cost of grading ranges from 15 to 50 cents per cubic yard; but in easy soil and moderate cuts, it generally varies from 25 to 35 cents. It usually costs 3 to 5 cents a square yard to dress off the subgrade after it has been graded with drag or wheel scrapers, and to throw the material into wagons.

The cost of rolling the subgrade will depend upon whether it is rolled longitudinally only, or both longitudinally and transversely. With a self-propelled roller the cost of rolling, both transversely and longitudinally, will be about 0.6 cent a square yard, exclusive of interest, storage, and depreciation of the roller.

The cost of the concrete foundation will vary with the price of cement, the proximity of broken stone or gravel, the character of the concrete, etc. Ordinarily the materials for a 6-inch course will cost 50 to 60 cents per square yard, and the labor 6 to 8 cents per square yard.

The price of bricks will vary with their size, the locality, and the freight rate. Previous to 1916 there was no uniformity in size, common sizes for the wearing face being $3\frac{1}{2}$ by $8\frac{1}{2}$ inches, $3\frac{3}{4}$ by 8, and 3 by 9; and some brands requiring 42 for a square yard, some 40, and some 38. Since the beginning of 1916 there has been a vigorous attempt to have all paving bricks of standard size, or rather to have the wearing face $3\frac{1}{2}$ by $8\frac{1}{2}$ inches, of which 40 make a square yard of pavement. In 1915, before the disturbance of prices due to the Great European War, the average price at the plant for standard blocks 4 inches deep was about $15.00 per thousand, or 60 cents per

square yard; but in 1917 for various reasons the price was practically 50 per cent more. There is no difference in price between wire-cut lug and re-pressed bricks. In estimating the freight it may be helpful to know that a brick $2\frac{1}{2} \times 4 \times 8\frac{1}{2}$ inches weighs about 7 lb., and a block $3\frac{1}{2} \times 4 \times 8\frac{1}{2}$ inches about 9.75 lb. In estimating freight, the fact should not be overlooked that for one reason or another a considerable number of bricks are rejected. With careful grading at the kiln the broken and rejected brick is likely to be 1 to 2 per cent.

In the early history of brick paving it was customary for the contractor to buy brick by the thousand; but the contractor claimed that the manufacturer did not cull the brick sufficiently carefully at the kiln, and consequently the rejections on the job were unduly great. For a time it became customary to buy the brick f.o.b. destination at a stated price per square yard in place in the pavement; but under this plan, the manufacturer claimed that the contractor did not use proper care in handling the bricks, did not keep them clean, used good brick instead of chipped or broken brick in making closures, and left good bricks along the finished pavement. At present it is customary to sell the brick by the thousand f.o.b. destination. The usual price is $25.00 per thousand f.o.b. destination.

The cost of hauling and piling on the side of the street is about $1.50 per thousand for a haul of 1 mile, of which sum about half is the cost of loading and unloading, and half the cost of team and driver; but this cost for team and driver necessitates the use of three wagons with each team.

The cost of setting blocks of which 40 make a square yard varies from 4 to 6 cents per square yard.

The cost of turning the chipped brick and replacing the rejected ones will depend mainly upon the severity of the inspection and upon the degree of care employed in culling the brick before they are laid. In a particular case, 80 hours were required to turn the chipped blocks and to replace the rejected blocks with good ones, in 1,633 square yards of pavement, or, say, 1 hour for each 20 square yards. The blocks were $3 \times 4 \times 9$ inches, and about 2 per cent were turned and about 2 per cent were rejected.

For data concerning the cost of sand filler, see § 995; for cost of cement filler, see § 1006; and for cost of bituminous filler, see § 1013.

Examples of the actual cost of brick pavements are given in § 1041–48.

1040. In this connection it should not be overlooked that the cost of the pavement proper is usually not the only cost of improving the street when it is paved. For details see § 878.

1041. Examples of Cost. In the following examples an attempt has been made to present the data in such detail as to make clear the form of construction; but unfortunately it is not always possible to present information concerning important economic conditions, as freight rates, the condition of the wagon roads over which material is hauled, efficiency of labor, etc.

1042. *Sand-cushion Asphalt-filled Brick Pavement.* Table 56 gives the details of laying a brick pavement. The excavation was done with a Maney 4-wheel scraper (§ 154) and a 20-H.P. tractor. Wages were as follows: Common labor 20 cents per hour; brick setters, 55 and 40 cents; engine runner for concrete mixer, 30 cents; team, wagon, and driver, 50 cents per hour.

TABLE 56

COST OF SAND-CUSHION ASPHALT-FILLED BRICK PAVEMENT

In Central Illinois in 1916

ITEMS.	COST PER SQ. YD.	
	Partial.	Total.
SUBGRADE:		
Rough grading at 29.8 cts. per cubic yard	$0.137	
Surfacing and rolling with 10-ton roller	.040	$0.217
CONCRETE FOUNDATION, 6 inches of 1 : 3 : 5:		
Labor at 20 cts. per hour	.056	
Cement at $1.48 per barrel (net) on job	.227	
Gravel at $1.40 per cubic yard on job	.156	
Sand at $1.50 per cubic yard on job	.122	
Coal and water	.006	.568
SAND CUSHION, 1½ inches thick		0.640
BRICK, wire-cut lug, 3½×4×8½ inches:		
Purchase price, f.o.b. destination	.807	
Handling in car	.027	
Hauling to street—average 2,200 feet	.020	
Laying, contract price	.050	.904
JOINT FILLER:		
Asphalt, 12 lb. per square yard	.095	
Labor, heating and pouring	.060	.155
MISCELLANEOUS EXPENSE		.052
Total cost, exclusive of administration, tools and profits		$1.960

1043. *3-inch Brick Pavement.* Table 57 shows the cost of a brick pavement having a 4-inch concrete foundation, $1\frac{1}{2}$-inch sand cushion, 3-inch vertical-fiber brick wearing coat, and asphalt joint-filler.

TABLE 57

COST OF 3-INCH BRICK PAVEMENT IN FALLS CITY, NEB., IN 1914*

ITEMS.	COST PER SQ. YD.	
	Partial.	Total.
SUBGRADE:		
Rough grading	$0.03	
Surfacing and rolling	.015	$0.045
CONCRETE FOUNDATION, 4 inches thick:		
Cement at $1.63 per barrel	0.185	
Stone at $2.25 per cubic yard	.232	
Sand at $1.10 per cubic yard	.060	
Mixing and placing	.050	.527
SAND CUSHION, $1\frac{1}{2}$ inches, at $1.10 per cubic yard	.....	.046
BRICK, vertical-fiber, 3 inches deep, f.o.b destination	0.70	
Unloading and hauling	.05	
Preparing cushion and setting brick	.04	
Rolling	.006	.796
JOINT FILLER:		
Bituminous material	0.12	
Applying	.03	.150
INCIDENTAL EXPENSES	.....	.017
Total, exclusive of administration, depreciation, and profits	.....	$1.581

* *Engineering News*, Vol. 73 (1915), p. 223.

1044. *Brick Roads in New York.* Table 58, page 548, shows the average cost of a great number of brick roads built in New York by the State Highway Commission in 1912 and 1913.* The roads were 15 feet wide, had 5-inch concrete base, 6-inch concrete edging, sand cushion, and grout filler. The cost below includes engineering expenses.

1045. *Monolithic Pavement.* Table 59, page 548, shows the labor and materials required for a monolithic brick pavement 33 feet wide, with 4-inch brick, and 1-inch special expansion joints every 82 feet. Table 60, page 548, shows the labor cost of this job.

* *Engineering News*, Vol. 70 (1913), p. 1149.

TABLE 58

AVERAGE COST OF BRICK ROADS IN NEW YORK IN 1912 AND 1913

ITEMS.	TOTAL COST.	
	Per Cent.	Per Mile.
Excavation	9.0	$2 200
Drainage structures	2.8	700
Subgrade and foundation	25.9	6 300
Brick wearing-course and edging	60.1	14 700
Minor expenses	2.0	500
Total	100.0	$24 400

TABLE 59

AMOUNT OF LABOR AND MATERIALS FOR MONOLITHIC BRICK PAVEMENT*

Central Illinois, 1916

Labor.	Hours per Sq. Yd.	Materials.	Cu. Ft. Per Sq. Yd.
BASE AND BED:		CONCRETE BASE, 4 inches:	
laborers	0.2305	1 : 6 cement	0.5
engine runner	.0154	gravel	3.000
sub-foreman	.0138	BEDDING MORTAR, $\frac{1}{4}$-inch:	
BRICK SETTING:		1 : 2 cement	.094
laborers	.1772	sand	.188
setters	.0227	GROUT, 1 : 1:	
filling joints	.0887	cement	.144
spreading sand	.0048	sand	.144
OVERHEAD:		TOP COVERING:	
timekeeper	.0171	sand	.188
foreman	.0171		
water boy	.0171		

TABLE 60

COST OF LABOR FOR MONOLITHIC BRICK PAVEMENT*

Central Illinois, 1916

ITEMS.	COST PER. SQ. YD.
Concrete base, 4 inches of 1 : 6 gravel	$0.0649
Setting brick, $3\frac{1}{2} \times 4 \times 8\frac{1}{2}$ inches	.0525
Filling joints with 1 : 1 grout	.0244
Spreading top covering of sand	.0011
Total cost of labor	$0.1429

* *Engineering News*, Vol. 76 (1916), p. 1219.

1046. *Brick on Old Macadam.* Table 61 shows the cost of laying a new brick pavement on an old macadam base by the Street Department of Carlisle, Pa. The macadam was spiked with a 13-ton 3-wheel self-propelled roller, excavated to subgrade, surfaced with hand picks, and rolled. The bricks were rolled with a 5-ton roller drawn by 12 men.

TABLE 61

COST OF NEW BRICK PAVEMENT ON OLD MACADAM FOUNDATION*

ITEMS.	COST PER SQ. YD.
Grading and rolling subgrade	$0.1126
Placing 5 inches of concrete in pipe trenches	.0848
Cushion course,—limestone screenings	.0543
Brick f.o.b. destination	.8600
Unloading and hauling brick	.0777
Laying brick	.0376
Rolling brick by manual labor	.0062
Grouting joints	.0845
Expansion joints, longitudinal and transverse	.0353
Top coating of sand	.0047
Total	$1.3587

* *Engineering News*, Vol. 72 (1914), p. 1263.

1047. *Semi-monolithic Brick on Old Macadam.* Table 62, page 550, shows the cost of laying a semi-monolithic brick pavement on an old macadam road. A 2-inch dry 1 : 4 mixture of cement and sand was used for the bedding course. The water cost nothing except the piping. The self-propelling roller used on the subgrade was loaned, and no charge therefor is included. Common labor received 20 cents per hour, and team and driver $6.00 per day.

1048. *Cost in Various Cities.* Table 63 and 64, page 550 and 551, shows the cost and several details of 3-inch and 4-inch brick pavements in various cities. A few cities use $3\frac{1}{2}$-inch brick, and a few $2\frac{1}{2}$-inch; but none of these are given here.

1049. MERITS OF BRICK PAVEMENTS. Bricks as a paving material have some attractive features. 1. They may be had in small units of practically uniform size. 2. They may be had in large or small quantities. 3. They may be laid rapidly without special expert labor. 4. When ailing pipes or other causes necessitate the disturbance of the pavement, ordinary tools and intelligence can restore the original surface. 5. Brick pavements give a good foothold for horses. 6. They do not wear slippery. 7. They

TABLE 62

Cost of Semi-monolithic Brick Pavement on Macadam*

Alton, Illinois, 1915

Items.	Cost per Sq. Yd.	
	Partial.	Total.
Labor:		
Grading, setting forms, building barricade	$0.084	
Placing mortar bed and laying brick	.087	
Mixing and applying 1 : 1 grout filler	.027	$0.198
Brick: rattler loss 25%		.560
Mortar Bed:		
Sand—0.083 ton at $0.82	.068	
Cement—0.079 barrel at $1.35	.105	0.173
Grout Filler:		
Sand—0.008 ton at $0.82	.007	
Cement—0.036 barrel at $1.35	.047	.054
Materials for Forms:		
Lumber at $20 per M—salvage at 67%	.009	
Template	.008	
Stakes and nails	.002	0.020
Miscellaneous:		
Depreciation on small tools and water line, teaming, etc.		0.038
Cleaning Up		.017
Total, exclusive of administration and profits		$1.060

* *Engineering Record*, Vol. 73 (1916), p. 414.

TABLE 63

Cost of 3-Inch Brick Pavements in Various Cities in 1916*

Locality.		Sq. Yd. Laid in 1916.	Foundation.		Bed Course.		Filler.		Cost Per Sq. Yd.
State.	City.		Thickness, inches.	Proportions.	Thickness, inches.	Kind.†	Kind.‡	Proportions.	
Kansas	Arkansas City	26 132	4	1 : 2 : 5	1½	S	A	.....	$1.81
	Ottawa	14 000	4	1 : 3 : 5	2	S	A	.....	1.57
	Parsons	6 208	4	1 : 3 : 5	1½	S	A	.....	1.63
	Salina	27 461	5	.....	1½	S	A	.....	1.92§
	Topeka	46 000	5	1 : 2½ : 5	1½	S	A	.....	1.77¶
Missouri	Sedalia	12 345	4	1 : 3 : 6	1½	S	A	.....	1.66
Nebraska	Fremont	20 809	4	1 : 3 : 5	1½	S	A	.....	2.04
	Lincoln	.....	5	1 : 3 : 6	2	S	A	.....	1.95
Oregon	Astoria	3 418	5	1 : 3 : 5	.....	M	G	1 : 3	2.70‖
Texas	Houston	17 500	6	1 : 3 : 6	¾	M	A	.....	2.45
	San Antonio	41 571	5	1 : 3 : 6	1½	S	A	.....	2.50

* *Municipal Engineering*, Vol. 52 (1917), p. 128–30.

† S = sand; S–C = sand-cement; M = mortar.

‡ A = asphalt; G = grout.

§ $2.15 with 4-inch re-pressed brick.

¶ $1.97 with 4-inch re-pressed brick.

‖ 2¾-inch brick.

TABLE 64

COST OF 4-INCH BRICK PAVEMENTS IN VARIOUS CITIES IN 1916 *

LOCALITY		Sq. Yd. Laid in 1916.	FOUNDATION.		BED COURSE		FILLER.		Cost Per Sq. Yd
State.	City.		Thick-ness.	Propor-tions.	Thick-ness.	Kind.†	Kind.‡	Propor-tions.	
California	Los Angeles	1 800	4″	1 : 3 : 6	1.5–2″	S	.....	.....	$2.52
Illinois	Alton	51 510	4	1 : 3 : 6	1	S-C	G	.....	1.65
	Champaign	30 000	6	1 : 3 : 5	1½	S	.....	.....	1.81
	Danville	42 000	5	1 : 3 : 5	1	S-C	G	1 : 1	1.72
	Galesburg	17 760	4	1 : 3 : 6	1	S	A	.....	1.76
	Mattoon	32 269	5	1 : 4½ : 8	1	S	G	1 : 1	1.63
	Peoria	36 536	4–5	1 : 3 : 5	1–2	S	G	1 : 1	1.60
Indiana	Crawfordville	4 108	4	1 : 3 : 5	1½	S	G	1 : 1	1.30
	Ft. Wayne	21 005	6	1 : 3 : 6	2	S	G	.....	1.79
	Muncie	12 000	6	1 : 3 : 6	2	S	G	1 : 1	2.03
	New Castle	19 408	5	1 : 3 : 6	.....	S-C	G	1 : 2	1.60
	Wabash	2 575	6	1 : 3 : 6	1½	S	G	1 : 1	2.25
Kansas	Leavenworth	4 717	5	1 : 3 : 5	2	S	G	1 : 1	1.80
Kentucky	Louisville	59 758	6	1 : 3 : 6	1½	S	G	1 : 1	1.81
Mass.	Fitchburg	13 844	5	1 : 2 : 4	1	S	G	.....	2.77
Michigan	Detroit	71 800	6	1 : 3 : 6	1	S	G	.....	2.14
	Grand Rapids	34 512	5	1 : 3½ : 7	1½	S	G	1 : 1	1.90
	Port Huron	2 572	5	1 : 2 : 5	1	.....	G	1 : 2	1.94
New York	Amsterdam	4 310	6	1 : 3 : 6	1	M	G	.....	2.50
	Jamestown	19 947	5	1 : 6	1½	S	G	1 : 1	2.08
	Poughkeepsie	25 000	5	1 : 3 : 6	1	M	G	1 : 1	2.16
Ohio	Canton	50 120	5	1 : 3 : 5	1	S	.....	.....	1.60
	Findlay	34 637	6	1 : 3 : 5	1½	S	G	1 : 1½	1.74
	Lakewood	22 223	6	1 : 3 : 6	1½	S	G	1 : 1	1.82
	Toledo	63 121	6	1 : 3½ : 6	1	M	A	.....	2.04
	Warren	42 000	5	1 : 3 : 6	2	S	G	1 : 1	1.80
	Youngstown	42 333	6	1 : 3 : 6	2	S	G	1 : 1	2.10
S. Carolina	Greenwood	15 000	4	1 : 3 : 6	1½	S	G	1 : 1	1.95
Washington	Seattle	112 581	5–6	1 : 3 : 6	.....	S-C	G	1 : 1½	2.55
Wisconsin	Beloit	14 488	5	1 : 3 : 6	1½	S	A	.....	1.99
	Racine	39 326	5	1 : 3 : 5	2	S	G	.....	2.15

* *Municipal Engineering*, Vol. 52 (1917), p. 128–30.
† S = sand; S-C = sand-cement; M = mortar.
‡ A = asphalt; G = grout.

are adapted to all grades. 8. They have low tractive resistance, particularly if the joints are filled with cement grout. 9. They are not specially noisy when properly laid. 10. Brick pavements yield no mud or dust. 11. They are easily cleaned. 12. If the joints are filled with sand, they are only slightly absorbent; and if filled with hydraulic or bituminous cement, they are non-absorbent. 13. Brick pavements have a pleasing appearance. 14. They are very durable, particularly if the joints are filled with cement grout. 15. They are cheap in consideration of their small cost of maintenance and long life.

1050. SPECIFICATIONS. The American Society for Testing Materials publish specifications for the standard rattler, the standard rattler test, and paving brick, copies of all of which can be had for a nominal sum of the Secretary. The American Society of Municipal Improvements publish complete specifications for brick street pavements having sand bedding course, and grout or tar or asphalt filler,

copies of which may be had for a nominal sum of the Secretary. The National Paving Brick Manufacturers Association publish complete specifications for all varieties of brick paving for both streets and roads, using wire-cut lug or re-pressed brick, copies of which may be had gratuitously of the members of the Association and of the Secretary, Brotherhood Building, Cleveland, Ohio. The Western Paving Brick Manufacturers Association publish specifications for all varieties of brick paving including the use of vertical-fiber brick, copies of which may be had gratuitously of members of the Association, or the Secretary, Dwight Building, Kansas City, Missouri. The Dunn Wire-cut Lug Brick Co., Conneaut, Ohio, an organization to promote the use of wire-cut lug brick by securing good and economical brick pavements, publish a complete set of specifications for wire-cut lug brick-paving, which may be had gratuitously. Many of the State Highway Commissions publish complete specifications for brick paving, which can doubtless be had gratuitously by residents of the respective states.

Art. 3. Maintenance

1052. The maintenance of pavements has never received attention in proportion to either its economic importance or the comfort of the user. This is particularly true of brick pavements, partly because they are comparatively new, and partly because the material not being subject to decay the need of maintenance has been over-looked. There has been no comprehensive diagnosis of the diseases of brick pavements, nor have any effective remedies been developed.

1053. Repairs of Brick Pavements. The more common matters that need attention in the maintenance of brick pavements are: (1) holes due to soft brick, (2) depressions due to shrinkage or flow of the sand cushion, (3) depressions due to sinking of foundation, (4) depressions due to settlement of trenches, (5) defects at transverse expansion joints, (6) defective grouting, (7) bulges, (8) longitudinal cracks, (9) re-laying pavements in patches and cuts, and (10) re-surfacing worn pavements.

1054. Soft Brick. A soft brick in the pavement wears away and makes a hole. Each wheel, particularly a steel-tired one, dropping into the hole crushes and chips the adjoining bricks even though they are hard, and the hole gradually increases in size and depth. When such a brick shows itself it should be cut out and be replaced

with a good one. The defective brick must be cut out with a chisel and hammer, the joints adjacent to it must be cleaned, and the bedding course must be removed. If the bedding course is sand, it must be carefully compacted; and if it is mortar, a new bed must be laid. After the new brick has been placed and firmly settled into the bedding course, and found to conform to the general surface of the pavement, the joints should be filled. If the joint filler is grout, the new brick should be dampened before the grouting is done, and care must be taken to see that the sand cushion has not pushed up into the joint; and after the joint is filled, the spot should be barricaded until the cement has set.

The patch should be barricaded for at least a day or two. Theoretically, this time is far too short for the cement grout to gain its full strength; but experience seems to show that a day or two is reasonably safe. The explanation of this anomalous result is that the spot being small, there is not much probability that a wheel carrying a maximum load will go over the spot until the cement grout has gained sufficient strength to hold it. Obviously then, the denser the traffic or the heavier the loads, the longer the barricades should remain.

If the brick are not quite uniform in quality, there may be so many soft bricks as to make it impracticable to remove each soft one, in which case the pavement must continue in service until it is resurfaced as described in § 1063, 1068, or 1069, or until it is replaced with a new pavement. The possibility of this condition arising is the reason for making the rattler test in such a way as to secure information as to the uniformity of the brick; and is also a reason for carefully inspecting the bricks after they are laid.

1055. Shrinkage of Sand Cushion. A common defect of brick pavements having a sand cushion is the shrinking of the cushion away from the brick, due probably to the sand being wet when the bedding course was spread. If the joints are filled with sand, the first evidence of the shrinkage of the cushion is a shallow saucer-like depression of the surface of the pavement. The remedy is to take up the low spot and re-lay the sand cushion. If the spot is not repaired, the depression is likely to be enlarged by the impact of passing wheels and the flow of the sand cushion. The flow of the sand cushion sometimes gives rise to broad shallow ruts, particularly on a street having a street-car track, since then the travel is concentrated on a narrow strip.

If the joints between the bricks are filled with cement grout, the

first evidence that the sand cushion has shrunk away from the brick is a rumbling noise when a steel-tired wheel goes over the spot. Tapping the surface of such a pavement with a hammer will reveal many such hollow spots. Such spots finally break down by the shearing of the joint filler. After this is done, water enters through the broken joints, and freezing lifts the pavement; and sometimes breaks other joints, and perhaps tilts a portion of the pavement and thereby roughens the surface. The examination of any sand-cushion pavement after it has been in service a year or two, will show a number of such breaks. The only remedy for this defect is to cut out the low spot and re-lay it. Many old pavements have so many such breaks that it is impracticable to repair them. The adequate preventive is not to use a sand cushion, or at least not a thick one. For a discussion of the method of resurfacing a brick pavement, see § 1063, 1068, or 1069.

1056. Settlement of Foundation. Sometimes a round depression is due to the settlement of a spot of the subgrade. It can not always be determined from a surface examination whether the defect is due to the shrinkage of the sand cushion or the settlement of the subgrade. To determine the cause, remove the wearing coat and the bedding course, and examine the top of the foundation for a crack near the edge of the depression. If the foundation is broken, it should be taken out, and the cause of the settlement be sought for. Perhaps it is due to lack of consolidation at the time of construction, or perhaps it is due to a leaking pipe or a spring. If it is due to the first, the remedy is thorough tamping; if to a leaky pipe, the remedy is obvious; and if to a spring, then adequate drainage must be provided. After the causes have been removed, the pavement must be replaced as described in § 1061.

1057. Settlement of Trench. The settlement of the back-filling of a trench is one of the most common and most serious defect in pavements. The settlement over a longitudinal trench is more noticeable but less damaging than that over a transverse trench. The prevention during construction is discussed in § 764–70.

When a pavement sinks over a trench, it is difficult to eliminate the defect. The first step is to remove in succession the wearing coat, the bedding course, and the foundation. The second step is to consolidate the back-filling; but this is not easily done. During construction, if the trench is not too deep and if it was not back-filled under very unfavorable conditions, the back-filling can usually be consolidated fairly well by rolling (§ 763); but this is impracticable

after the pavement is laid. Under some conditions flooding (§ 766) may be worth trying. The most feasible way is to dig out the trench and replace the material with adequate tamping (§ 767–69). The usual method is simply to fill the trench, generally a little more than full, and re-lay the pavement, allowing it to be a little high with the expectation that it will settle to place. But sometimes the pavement does not settle, and sometimes it settles too much; and then in either case, another trial is needed to secure a good surface.

Sometimes an attempt is made to remedy such a defect by laying a thicker concrete foundation over the trench and allowing the slab to extend laterally beyond the trench; but usually such a remedy is not effective except perhaps where the trench is comparatively narrow and where the banks of the trench are fairly solid. A radical remedy would be to dig out the trench and fill it with sand, or gravel, or a very lean concrete (§ 770). The difficulty of removing this defect is a reason in favor of good original construction.

For a discussion of the method of replacing the brick in making such a repair, see § 1061.

1058. Transverse Contraction Joints. Transverse contraction joints are a common cause of deterioration in a brick pavement having grout filler. The action of the joint in damaging the adjacent pavement has been explained in § 1019–20, and illustrated in Fig. 195, page 535. The only remedy in such cases is to remove the expansion joint and re-lay the pavement. For some hints concerning the method of re-laying the pavement, see § 1061.

1059. Defective Grouting. Defective grouting is a cause of serious deterioration in a brick pavement. In a pavement with a rigid filler, it is essential that the filler extend from top to bottom of the joints, as otherwise the pressure due to the expansion of the pavement will be concentrated on one portion of the joint, which will crush the filler and break the bond, and cause the pavement to wear as though it were sand-filled; or the pressure may cause the brick to spall or crush. There are two possible reasons for such defects: 1. The sand of the cushion course may have pushed up into the bottom of the joint when the bricks are rolled; and consequently the filler at the bottom of the joint will not be as rigid as that at the top. 2. The grout, particularly that of the second coat, may have been so thick as to bridge the joint and fill only the top of the joint. Fig. 201, page 556, shows a spot in which the grouting was defective. Notice that a rut has formed at the right of the defective spot, that a brick at the top of the spot is badly shattered, and that several bricks have

spalled. These defective spots are usually small in the beginning, but they gradually enlarge owing to the increased effect of impact and also to the effect of the water that penetrates such spots.

FIG. 201.—DEFECTIVE GROUTING.

These spots may be cut out by hand with chisel and hammer, or with a pneumatic chisel or chipping hammer as shown in Fig. 202.

FIG. 202.—PNEUMATIC CHISEL CUTTING OUT DEFECT.

In Baltimore the cost of toothing out a brick pavement having grout filler (see Fig. 204, page 559) was 18 cents per lineal foot by hand, and 2.76 cents per lineal foot with a pneumatic chisel.*

* *Municipal Engineering*, Vol. 52 (1917), p. 6.

In cutting out such a spot no half brick should be left, as otherwise there will not be sufficient bond between adjacent bricks. The joint-filler should be thoroughly cleaned from the edges of the toothed bricks, care being taken not to break the bond of the remaining bricks. The bedding course should be adjusted so as to bring the tops of the new bricks to the proper elevation. Care should be taken that the brick to be used in filling the patch are of exactly the same size as the old ones. The brick should be laid, tamped, and grouted as in the original construction.

1060. Bulge. A bulge is a buckling or heaving of the wearing coat of a brick pavement due to its expansion. Sometimes the bulge is simply a wave, sometimes a ridge having a crack at its crest, and occasionally an explosion or "blow-up" in which a number of bricks are thrown into the air with considerable force. Fig. 203

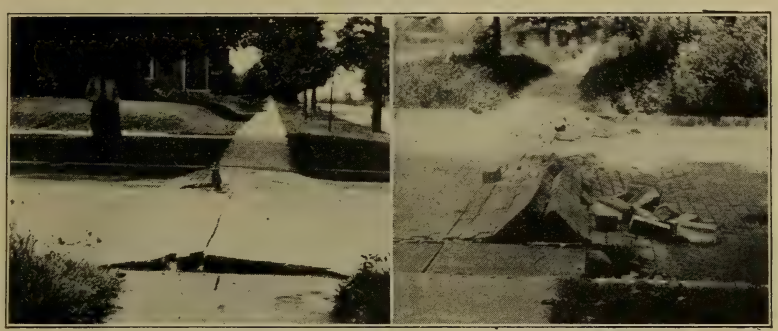


FIG. 203.—TWO BULGES IN BRICK PAVEMENT.

is a view of two upheavals. The right-hand example is a mild upheaval, and the left-hand one is a moderate explosion. A bulge usually occurs at a crowned foot-way crossing or a street intersection. Notice that both of the bulges shown in Fig. 203 occurred at a crowned foot-way crossing.

If a main street is paved and its crown is carried through the intersection with another street and later the latter is paved, the pressure due to the expansion of the pavement of the cross street against the abutments of the crown of the main street may cause the crown of the arch to rise with or without an explosion. The mildest form of this phenomena is simply lifting the pavement from the sand cushion, in which case the pavement will give out a rumbling sound as a wheel passes over it, and it will come back to place when the pavement cools. Or the pavement may be cracked near the

middle of the main street, in which case the pavement must be re-laid along the crack, since the pavement will not of itself return to its former position. Upheavals or cracks from this cause can be prevented by putting in an expansion joint where the pavement of the cross street abuts against that of the main street.

Sometimes a lateral pressure on the pavement will lift the crown from the sand cushion, as is shown by a rumbling when a vehicle goes over it; and in extreme cases the pavement will crack near the middle of the street. This lateral thrust may be due to an inadequate or obstructed expansion joint next to the curbs. A poured longitudinal expansion joint may become obstructed by pebbles or brick spalls dropping into the space or by the sand cushion's running into it, before the mastic is poured. The crown of the pavement may be lifted also by the expansion of freezing water in the soil behind the curbs.

An upheaval may occur in a level stretch of pavement due to defective grouting. If only the top of the transverse joints are filled, the pressure of the expansion is concentrated at the top of the joints; and if the joints over a considerable area are in like condition, they may all fail at once—usually with a loud report and a general upheaval of the affected area.

1061. Re-laying Pavement. If a brick pavement is to be maintained in a fair condition, it will frequently be necessary to re-lay the pavement over patches and also over openings made to lay or repair sewers, water or gas pipes, electric conduits, etc., for with the utmost care and foresight many such openings will be made (§ 656–57). The typical case is re-laying a pavement over a trench.

In making the cut in the pavement alternate brick will sometimes be broken in the middle, thus leaving three bricks with their ends in line, which would prevent a good bond of the new pavement with the old; and therefore these broken bricks must be " toothed out " so that only whole brick remain. This may be done by hand with a stout long-handled chisel and hammer, or with the pneumatic chisel (Fig. 202, page 556). After the broken brick are " toothed out," the cut will have the general appearance shown in Fig. 204. Next the joint-filler should be chiseled off from the brick that are " toothed out," care being taken not to break the bond of these bricks with those adjoining.

Before re-laying the concrete foundation, the soil in the trench should be thoroughly compacted; and particularly the soil that has run out into the trench from under the edge of the foundation, should

be replaced and rammed laterally to give a firm bearing. The concrete should then be laid and tamped as in the original construction. If the bedding course is sand, great care is necessary in packing or ramming it under the edge of the undisturbed pavement.

As far as they are available, the old brick should be cleaned and used, for they will match the others in size and color. If new brick are used, they should be of exactly the same width as the old

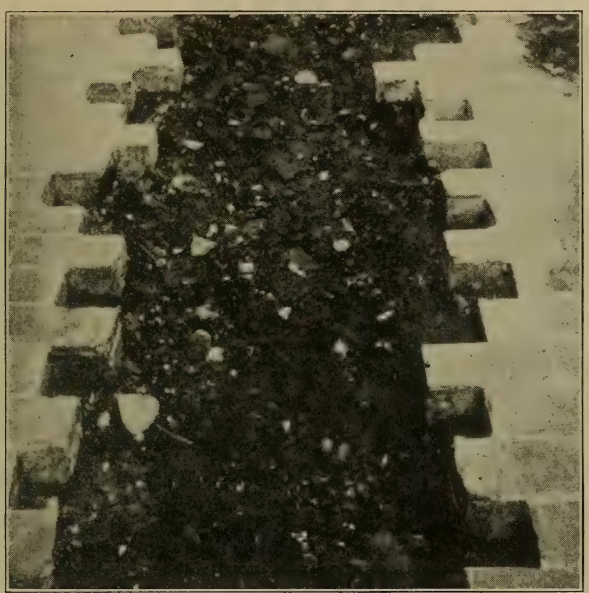


FIG. 204.—PATCH PROPERLY TOOTHED OUT.

ones so that the courses will match. The brick should be bedded in the sand or mortar bed-course so their upper faces conform to the surface of the pavement; and then the joints should be filled. If grout is used, two or three applications should be added as described in § 999–1004; and after the grout has taken an initial set, the patch should be covered with sand or straw which is kept wet for 3 or 4 days. In this connection, see the latter portion of the second paragraph of § 1054.

With care in making a re-placement, the patch can be made so that the original surface and strength of the pavement is fully restored; and if the work is well done, the patch will hardly be visible. Fig. 205, page 560, shows such a patch over a trench in a pavement in Cleveland, Ohio. This patch is visible only because of the differ-

ence in color of the old and the new brick. In that city are many such repairs which are scarcely visible.

Part of the reasons for this good work is that the back-filling of the trench is inspected and the pavement is re-laid by employees of the division of street repairs.

1062. Cracks. The only cracks requiring consideration are longitudinal ones, which are usually near the center of the road. The transverse cracks are usually narrower, and are less harmful. A

FIG. 205.—BRICK PAVEMENT RE-LAID OVER A TRENCH.

longitudinal crack is likely to develop into a rut. A longitudinal crack may be due to any one of several causes. 1. It may be due to the heaving action of frost under the edges of the foundation. 2. It may be due to the settlement of the edges of the foundation when the frost is out under the edges of the foundation and not under the center. 3. It may be due to the shrinkage of the soil under the edge of the foundation due to the soil's drying out. 4. It may be due to expansion as explained in the last two paragraphs of § 1060.

It is sometimes impossible to explain the cause of such cracks. They seem to be more common in the North than in the South; and hence it is concluded that frost is a common cause. They seem

to be less frequent the flatter the crown of the pavement; and they seem to be less frequent with a flat than with a crowned subgrade.

The only practicable thing that can be done with a longitudinal crack is to clean and fill it with a bituminous cement as described for concrete roads—see § 482.

1063. RE-SURFACING. Re-surfacing is a method of radical repairs. There are many sand-filled pavements so badly worn and so full of depressions as to be of but little value as a pavement, which may be used as a foundation for a new wearing surface. There are three methods that may be employed in re-surfacing such pavements, viz.: (1) covering the brick with a bituminous surface; (2) turning the brick upside down and re-laying them; and (3) laying a new monolithic surface on the old pavement.

The bituminous surface may consist of either asphalt or tar.

1064. Asphalt Top. The asphaltic surface may be either asphalt concrete or a binder course and a wearing coat similar to that of a sheet asphalt pavement. When the work is well done in every particular, the result is very satisfactory; but there have been many failures, probably owing to the failure to meet one or more of the conditions necessary for success. There are several essential conditions to be fulfilled. 1. The original pavement must be absolutely rigid, and not show any vibration or settlement when a heavy load goes over it. The lack of rigidity in the original pavement or in portions of it which are re-laid preparatory to re-surfacing it, is one of the most common causes of failure of a bituminous top. 2. The surface of the old pavement must be leveled up by filling the depressions with concrete, so that the asphalt will be of nearly uniform thickness, as otherwise it will creep and loosen from the brick. Depressions deeper than 2 inches should be filled with hydraulic concrete; but depressions less than 2 inches deep may be filled with the mixture for the asphalt binder course (§ 812–24). 3. The asphalt must be of good quality and proper consistency. 4. The pavement must be perfectly clean. The dirt must not only be removed from the surface but also from the cracks for at least $\frac{1}{2}$ an inch. This can be done with wire brooms, but it requires great care. The dirt can be removed more effectively with a fire hose than by sweeping. 5. The brick should be perfectly dry when the asphalt is applied. 6. The old brick should not be cold when the asphalt is applied. If a surface heater (Fig. 161, page 450) is available, it is wise to warm the old brick before applying the asphalt. 7. Apply a paint course of asphaltic cement thinned with naphtha, at the rate of not more

than a gallon to the square yard. Dust or dampness or cold will prevent the paint coat from adhering perfectly. 8. As soon as the naphtha has fully evaporated from the paint coat, and while it is still perfectly clean, the sheet asphalt should be laid and rolled.

The sheet asphalt may be either a binder course and a wearing coat of a total thickness of 2 inches, or a wearing coat alone having a thickness of 2 inches. The binder course and also the wearing coat are to be mixed and laid as described for the corresponding operations for a sheet asphalt pavement (§ 812–24 and § 825–45, respectively). Experience has shown that if it is possible, the asphalt surface should not be less than 2 inches thick at any point, as it is likely to creep and form humps. This is due to the fact that in rolling the binder course or the wearing coat, the wide roller will be supported on the high points and not compress the asphalt in the holes; and later narrow tires will compress the asphalt in the holes and make a depression, and wheels dropping into these depressions will displace the asphalt and loosen it from the bricks.

1065. One of the most difficult questions encountered in planning to add a new surface to an old pavement is the matter of drainage. The curb or gutter that was only deep enough for the original pavement will be too shallow if a new 2- or 3-inch surface is put on top of the old. This difficulty is not as serious on streets having considerable longitudinal grade as on nearly level streets. On the latter, either of two things may be done,* viz.: 1. Take up the old brick and the foundation next to the curb (or next to the combined curb and gutter) for a width of 3 or 4 feet, and lay a new concrete foundation at such a height that when the old brick are re-laid and the asphalt is placed thereon, the gutter will be of suitable depth (or the top of the asphalt will be even with the top of the concrete gutter). 2. Take up the old brick for 3 or 4 feet next to the curb (or next to the combined curb and gutter) and lay concrete in this space making its upper surface next to the gutter of such a height that the asphalt when laid thereon will given sufficient depth of gutter (or will come even with the top of the concrete gutter), and making the top of its edge next to the undisturbed brick level with the top of the brick. Of course, both of these methods increase the transverse slope of the pavement near the curb, but usually this is not serious.

At street intersections that are not to receive an asphalt top, a

* Thomas H. Brannan, Superintendent Asphalt Streets, Columbus, Ohio, in Proc. Amer. Soc. Municip. Improvements, 1916, p. 107–8.

somewhat similar adjustment is necessary where the new asphalt top meets the pavement of the side street.

1066. Tar Top. Tar has not been used for this purpose as much as asphalt, but it has been employed enough to show that it can be made to give reasonably satisfactory results. The method of applying the tar is as follows: 1. The brick surface should be rigid, clean, dry, and warm as described in items 1, 4, 5, and 6 of § 1064. 2. All depressions more than 1 inch deep should be filled with hydraulic concrete. 3. All depressions less than 1 inch deep should be thoroughly painted with tar, and then be filled with $\frac{1}{4}$- to $\frac{1}{2}$-inch broken stone perfectly free from dust. 4. The tar is then applied substantially as described for bituminous carpets (§ 591–93), except that a greater quantity is applied, depending upon the degree the bricks are worn. Enough should be applied to have a layer of about $\frac{1}{8}$ of an inch thick on the face of the brick. The tar should be well brushed or rubbed into the joints with a wire broom. 5. As soon as the tar is rubbed into the joints, a half-inch layer of stone chips is applied as described in § 594–95.

When the surface is finished, it will have the appearance of a bithulithic pavement (§ 893), and will give good service for several years, depending upon the character and amount of traffic. When worn through, the surface can be renewed by the addition of a new coat of tar and screenings.

Water injures a tar surface, and hence this treatment is more permanent the better the drainage of the surface.

1067. Turning the Bricks. In Champaign, Illinois, in 1916, two experiments were tried of laying a monolithic brick pavement on the existing concrete base, turning and using the old bricks. The old pavement was laid on a 2-inch sand cushion, and the joints were filled with sand. The brick were badly worn.

The repair work was carried out as follows: 1. The concrete base was cleaned, and on it was laid a 2-inch layer of 1 : 3 : 2 gravel concrete for a bedding course. 2. The brick were thoroughly cleaned with wire brushes, and laid on the bedding course before the concrete had set. 3. The brick were rolled and grouted in the usual way (§ 991 and § 996–1002). 4. The street was barricaded for 15 days.

In one section, the brick were very badly worn, and varied in depth from $2\frac{1}{2}$ to 4 inches. About 10 per cent had to be replaced with new ones. No attempt was made to size them, and it was difficult to get a smooth surface. If the brick had been sorted, and

the most worn ones placed next to the curb and the least worn at the crown, it is believed a better surface would have been obtained with less labor. On the other section, the brick were not worn so much, and a good surface was obtained with much less trouble. The surface of this section compares favorably with that of a new monolithic pavement. The cost was 80 cents per square yard, which could doubtless be reduced with greater experience.

1068. Monolithic Brick Top. In 1917 near Danville, Ill., a new method of re-surfacing an old brick pavement was tried.* The pavement was on a suburban road which carries a dense and heavy traffic; and after considering asphalt, tar, and concrete as materials for the new surface, a monolithic brick surface with a thin concrete base was adopted. The concrete was one part of cement to four parts of fine, well-graded gravel; and its thickness varied from 1 to 5 inches according to the depth of the holes in the old pavement. Part of the new brick were 4 and part 3 inches deep. The concrete, the bedding course, and the brick were laid as described under monolithic pavements (§ 969, § 982, and § 996–1002, respectively). Fig. 206 shows two views of this work in progress. The cost was $1.65 per square yard; and the saving was substantially the cost of a new concrete base.

Fig. 206.—Putting a Brick Top on an Old Brick Road.

Obviously this method of re-surfacing would be inapplicable to a city street, on account of the difficulty of maintaining proper drainage.

1069. Cost of Maintenance. As stated in § 868, the City of Buffalo, N. Y., is noted for the completeness of its records of the cost of construction and maintenance of pavements. The following is a summary for the cost of maintenance of brick pavements for

* Harlan H. Edwards, *Engineering News-Record*, Vol. 79 (1917), p. 830–32.

the year ending June 30, 1916. Of the twenty brick pavements over twenty years old, two short streets have required no repairs; and the repairs on the other eighteen streets cost from 0.22 to 4.92 cents per square yard per year, all but six costing less than 0.85 cent per square yard per year. Of the fifty brick-paved streets from ten to twenty years old and out of guaranty, twenty have required no repairs; and the repairs on the other thirty have ranged from 0.04 to 1.58 cents per square yard per year, only three of these costing more than an average of 1 cent per square yard per year.* The average cost of repairs during 1915–16 on 231,355 square yards was 2.9 cents per square yard.†

* Report of Dept. of Public Works—Bureau of Engineering, 1915–16, p. 481–511.
† *Ibid.*, p. 70.

CHAPTER XVIII

STONE-BLOCK PAVEMENTS

1073. Stone-block pavements rank third in area among the permanent pavements, being exceeded by sheet asphalt and brick —see the tabular statement on page 320.

1074. CLASSIFICATION. The earliest pavements of ancient times consisted of irregular shaped blocks of stone more or less accurately fitted together. The form and size of the blocks have varied greatly from time to time, a fact which has given rise to different classes of pavements. A few of these will be briefly described.

1075. Roman Roads. The Roman roads so frequently referred to by modern writers are the earliest examples of stone-block pavements. The details of construction varied somewhat, but as a rule they were about as follows: The foundation was laid in a trench about 3 feet deep, with no attempt at underdrainage. The base was formed of one or sometimes two courses of large flat stones laid in lime mortar, and was usually about 15 inches thick. Upon this was laid a 9-inch course of small fragments of stone imbedded in lime mortar, the intention of this course apparently being to bind together the tops of the large stones in the course below. Next was laid a 6-inch layer of concrete, apparently to make a smooth bed to receive the stones of the top course. The wearing surface consisted of closely-jointed, irregular-shaped stones, about 6 inches thick. The total thickness of the road was about 36 inches. In and near the cities, the top course was formed of irregular blocks of basalt, porphyry, or lava, which had a top area of 4 or 5 square feet and a thickness of 12 to 15 inches. These blocks were dressed and fitted together with extreme accuracy, and were imbedded in cement. These ancient pavements have aptly been described as "masonry walls laid on their sides."

The Romans seem to have located their roads in straight lines,

running them toward prominent land-marks without much regard to the topography or to natural obstacles. They were wasteful of materials and labor, which, however, cost nothing but the lives of captives who were forced to build these roads for the armies of their captors. The results were roads which are remarkable chiefly for their cost, and which were inferior to modern pavements costing only one eighth to one quarter as much. The durability of these roads does not seem so remarkable when it is remembered that the traffic was light, and consisted mostly of footmen, unshod horses, and ox-carts having wooden wheels, and also that probably the surface of the road was kept covered with earth two or three inches deep.

1076. Cobble-stone Pavement. A cobble-stone pavement consists of cobble stones or small bowlders placed side by side upon a bed of sand or upon the natural soil. The stones, usually somewhat kidney-shaped, are selected with some relation to size, set on end side by side in holes dug in the sand or unconsolidated native soil by a laying tool, one end of which serves as a scoop and the other as a hammer to settle the stones in place, and lastly sand or fine gravel is spread over the surface to fill the spaces between the stones. Fig. 207 shows a transverse section of a cobble-stone pavement; and Fig. 208, page 568, shows the only tool used in laying it.

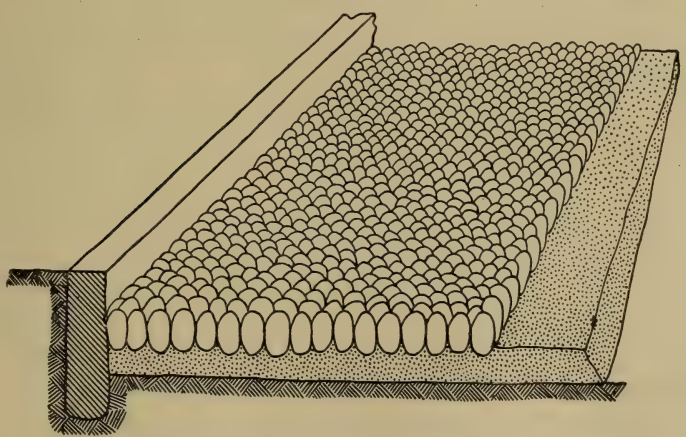


FIG. 207.—SECTION OF COBBLE-STONE PAVEMENT.

The earliest pavements in many of the older cities, both American and European, were of this type; and until about the beginning of this century on account of their comparatively low first cost were

quite common. In 1884, 93 per cent of all the pavements in Philadelphia were made of cobble stones; but in 1901 less than 6 per cent were of this kind. In 1902 Baltimore had 321 miles of cobble-stone pavement, —more than any other city in the United States,—over 90 per cent of the pavements being cobble stones. In September, 1901, New York City still had 229 miles of streets paved with cobble stones, but nearly all of them have been replaced with better pavements. Since the introduction of asphalt, brick, and bituminous pavements, and since the decrease in the cost of stone-block pavement by the introduction of improved methods of quarrying and manufacture, there is no excuse for the construction of cobble-stone pavements, and little excuse for their continuance. The construction of such pavements has been practically abandoned, and in some cities it has been prohibited by law—like theft and murder.

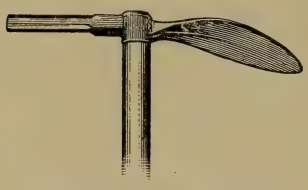


FIG. 208.—COBBLE-STONE HAMMER.

1077. Rubble Paving. In some cities having no cobble stones but having comparatively plenty of even bedded sandstone or limestone, the streets were paved by laying rough rubble stones flatwise, the stones being 4 to 6 inches thick and having a top surface of 4 to 6 square feet. The irregular joints between the stones were filled with spalls. The blocks chipped on the edges, wore round on top, and got out of place, thus making an exceedingly rough pavement.

1078. Belgian-block Pavement. This is a stone-block pavement made of blocks nearly cubical in form, from 5 to 7 inches on a side. For a time this form of pavement was very common in both Europe and America. The objections to the Belgian pavement are: 1, On account of the size and form of the blocks, it is difficult to keep them in place; 2, the blocks are of such a form as to give a poor foothold to horses; and 3, there is always a considerable length of joints parallel to the line of travel, which causes ruts to form in the pavement. Belgian blocks have usually been laid with their sides perpendicular and parallel to the sides of the street; but if a square block is to be used, it should be laid in courses diagonal to the street, so that no joints shall be parallel to the line of travel, a method which would add some extra expense. The Belgian block has been discarded in this country for the oblong block.

1079. Oblong Block Pavement. At present practically the only stone paving-blocks employed are about $3\frac{1}{2}$ to $4\frac{1}{2}$ inches wide,

8 to 12 inches long, and nominally 4 or 5 inches deep. They are laid on a concrete base with their longest dimension perpendicular to the line of the street. This is the form of stone-block pavement that will be considered in detail in this chapter.

1080. Durax Pavement. This form consists of granite cubes from $2\frac{1}{2}$ to 4 inches on a side. This form of pavement will be considered only briefly—see § 1117.

ART. 1. THE STONE

1081. As stone-block pavements are employed only where the travel is heavy, the material of which the blocks are made should be hard enough to resist the abrasive action of the travel, and tough enough to prevent being broken by the impact of loaded wheels. The hardest stones will not necessarily give the best results in the pavement, since a very hard stone usually wears smooth and becomes slippery, and the edges of the block chip off and the upper face becomes rounded, thus making the pavement very rough. A hard stone may be necessary under a heavy traffic; but under medium traffic a softer stone may give more satisfactory results.

The stone could be tested to determine its strength and durability much as paving bricks are tested, but it is not known that any such tests have been made. An examination of a stone as to its structure, the closeness of its grain, its homogeneity, etc., may assist in forming an opinion as to its value for use in a pavement; but in the present state of our knowledge, a service test in the pavement is the only certain guide.

Granite, trap, sandstone, and limestone have been used for paving blocks.

Granite paving blocks are much the most common, and ordinarily the term granite-block pavement is employed as being synonymous with stone-block pavement.

1082. GRANITE. This is a massive, unstratified, granular rock composed essentially of quartz and feldspar; but almost always containing other components, such as mica, hornblende, and tourmaline in varying proportions. The quartz and the feldspar are called essential ingredients, since their presence is necessary to form a granite; while the other constituents are called accessories, since they merely determine the variety of the granite. The term granite is popularly applied to any feldspathic granular rock, and includes gneiss, syenite, and porphyry, or any crystalline rock

whose uses are the same as granite. Gneiss is a rock of granitic composition that has a decided banding or parallel arrangement of its mineral constituents. Syenite is a granitic rock containing no quartz. Porphyry is popularly any fine-grained compact rock having large crystals scattered throughout its mass.

Granite varies in texture from very fine and homogeneous to coarse porphyritic rocks in which the individual grains are an inch or more in length. The color may be red, dark mottled, light to dark gray, or almost black. The durability is closely related to the accessory minerals present; and although granite is popularly regarded as the hardest and most durable stone, there are some notable exceptions. A quartoze granite, one in which quartz predominates, is too brittle for paving purposes; a feldspathic granite, one containing an excess of feldspar, is too easily decomposed; and a micaceous granite, one containing considerable mica in parallel laminas, is too easily split for use in paving blocks. Gneiss is usually too much stratified to make a good paving material. Syenite is one of the gest materials for paving blocks, and usually the darker the color the better the stone.

The crushing strength of granite usually lies between 15,000 and 20,000 lb. per square inch. It is customary to specify that the granite shall have a toughness of not less than 9 (§ 342), and a French coefficient of wear of not less than 11 (§ 343).

A most important property possessed by all granitic rocks is that of splitting in three planes at right angles to each other, so that paving blocks may readily be formed with nearly plane faces and square corners. So far as discovered, this valuable property is possessed only by the granitic and trappean rocks. This property is called rift or cleavage, and was caused by pressure before the rock was consolidated. The fine-grained granites possess the most perfect rift, and it decreases as the size of the grains increase, so that a coarse-grained variety is likely to require considerable dressing to bring the face of the block to a plane surface.

1083. Granite paving-blocks are produced in large quantities in Wisconsin, Maine, New Hampshire, Massachusetts, North Carolina, Georgia, and Minnesota. The order in the above list is that of the number of blocks produced in 1916, the first two states producing more than all the others. In recent years the production of granite paving-blocks has greatly fallen off, apparently more than one half, probably owing to the substitution of asphalt and brick for stone blocks for paving purposes; but the quality has greatly

improved, partly in response to a demand for smoother block-pavements; and partly by using smaller blocks, which can be cut more accurately; and partly by abandoning the use of the hardest granites and using the softer and finer-grained varieties, which split more easily and regularly and make a better wearing surface.*

1084. TRAP. This is a popular term applied to any dark-colored, massive, igneous rock. Owing to the difficulty of making them, trap is not much used for paving blocks.

1085. SANDSTONE. Sandstones are rocks made up of grains of sand which are cemented together by siliceous, ferruginous, calcareous, or argillaceous material. The texture of the stone varies according to the sizes of the sand grains, of which there are all gradations from those that are so fine as to be barely discernible to those that are very coarse. The hardness, strength, and durability of the stone is dependent upon the character of the cementing material. Only the harder and tougher sandstones, generally those in which the cementing material is siliceous, are used for paving. Sandstone paving-blocks are common in the Lake and Western cities. The principal quarries from which sandstone paving-blocks are obtained will be briefly described.

1086. Medina Sandstone. This stone is found in the state of New York, extending from Oneida and Oswego counties on the east along the shores of Lake Ontario westerly to the Niagara river. It is generally a deep brownish red in color, though sometimes light and yellowish, and in a few localities gray. The stone is evenly bedded, and the beds are divided into blocks by systems of vertical joints, generally at right angles to each other, an arrangement which greatly facilitates the work of quarrying. It absorbs $2\frac{1}{2}$ to $3\frac{1}{2}$ per cent of water, but it is not materially affected by alternate freezing and thawing.

This stone is much used for paving in the Lake cities, where it is often preferred to granite, since it does not wear slippery.

1087. Potsdam Sandstone. This formation is worked at a number of places in the state of New York, the largest quarries being near Potsdam. That quarried at Potsdam is hard and compact, evenly grained, and reddish in color. It is largely used as a building stone and to a considerable extent for pavements.

1088. Colorado Sandstone. In Boulder County, Colorado, are several deposits of sandstone that furnish stone for paving purposes.

* For an interesting and elaborately illustrated article on the Manufacture of Granite Paving Blocks, see *Engineering News*, Vol. 73 (1915), p. 376–81.

It splits easily, and breaks readily at right angles, so that it is formed into flagging, curb stones, and paving blocks without difficulty. It is hard and tough, and wears well in a pavement. It is never slippery; and after a little wear forms a smooth and pleasing pavement, very similar to one made of Medina stone.

1089. Sioux Falls Quartzite. This is a metamorphic sandstone quarried at Sioux Falls, South Dakota. The stone is almost pure silica with only enough iron oxide to give it color, which varies from light pink to jasper red. It is very close grained, and will take a polish almost like glass. It is said to be the hardest stone in this country. Its crushing strength is about 25,000 lb. per square inch. It possesses a remarkably good rift and grain, although not so perfect as that of granite. It is used considerably as a paving material, being shipped as far east as Chicago; but it wears smooth with a glassy surface.

1090. Kettle River Sandstone. This is a fine-grained, light-pink sandstone, found in large quantities at Sandstone, Minn., about a hundred miles north of Minneapolis, which has been used for paving purposes in Wisconsin and Minnesota. The stone wears flat, does not polish, and approaches granite in its resistance to crushing.

1091. LIMESTONES. These differ greatly in structure, from a light friable variety highly charged with fossils to a hard compact rock denser and heavier than granite. The thin bedded varieties are easily broken into paving blocks. Although some varieties of limestone are very dense and strong, it wears unevenly when used as a paving material, and the blocks are speedily shivered by traffic and split by frost, owing to the fact that the lamination is vertical.

ART. 2. CONSTRUCTION

1093. Fig. 209 shows a transverse section of the better form of stone-block pavements.

1094. FOUNDATION. The method of preparing the subgrade has already been discussed—see Art. 1, Chapter XV. Formerly the foundation always consisted of a bed of sand upon the natural soil (§ 966), but at present it is nearly always a layer of concrete (Art. 2, Chapter XV). Stone-block paving is laid only on streets subject to heavy travel.

1095. BEDDING COURSE. On the concrete foundation must be spread some material to even up the surface of the concrete and

to give a good bed for the blocks. The smoother the surface of the concrete and the less the variation in the depth of the blocks, the thinner can be the cushion coat. Sand has generally been used for the bedding course, but recently cement mortar has been employed tentatively.

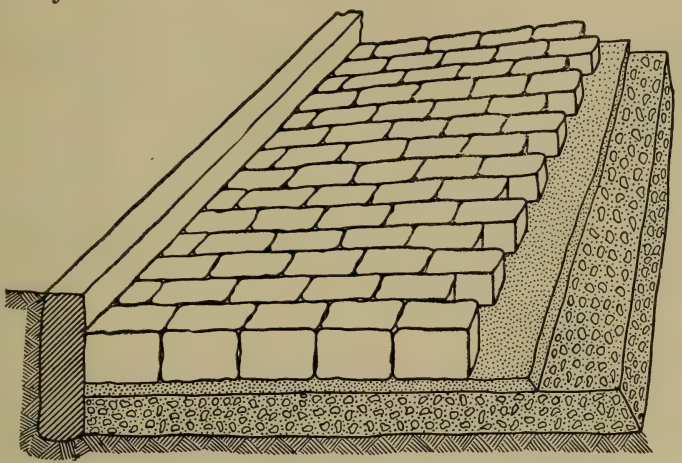


FIG. 209.—SECTION OF STONE-BLOCK PAVEMENT.

1096. Sand Cushion. The sand should be fine, clean and dry. The finer the sand the better. It should contain no pebbles greater than $\frac{1}{4}$ inch in diameter. The sand should be clean so as to compress uniformly; and it should be dry so it will not shrink away from the blocks in drying out (§ 1055).

In spreading the sand cushion for brick pavements, great care is taken to secure a bed of uniform thickness and density (§ 972), so that when the pavement is rolled, the surface will be smooth; but stone-blocks are not as uniform in size as bricks, and hence they must be settled to place by ramming each individual block, and therefore it is not necessary to spread the sand for stone-blocks with as much care as for bricks. However, for the best results, it is wise to spread the sand with a shovel as uniformly as possible, and then rake it to loosen up any spots that have been consolidated by throwing down a shovelful of sand and to level it off and secure a layer of uniform thickness and density. After the sand is leveled off it should not be stepped upon; and in laying the blocks the men should stand upon those already placed. However, these precautions are seldom taken; and usually the blocks are deposited on the sand cushion and the man who sets them stands upon the sand cushion while at work.

The thickness of the bed should vary with the accuracy of the dressing of the blocks. If the more inaccurately dressed blocks (paragraph 1, § 1100) are employed, a depth of 2 inches may not be too much; but if the most accurately dressed blocks (paragraph 2, § 1100) are used and if the top of the concrete bed is reasonably smooth, the sand cushion need not be more than 1 inch. The sand cushion should be no thicker than is necessary to give a good bed for the blocks.

1097. For a statement of the objections to a sand cushion for brick pavements, see § 977–78. These objections apply with nearly equal force to stone-block pavements.

1098. Mortar Bedding Course. In view of the success of the monolithic brick pavement, particularly for rural roads (§ 979–82), it has been proposed to lay granite blocks in a mortar bedding-course; but there has been only a little experience with this form of construction. The mortar bedding course could be a dry mixture of cement and sand (§ 979) on a concrete base partially set, or a coat of green mortar on a concrete base which has not taken initial set (§ 982).

Some claim that with a monolithic stone-block pavement on city streets it would be too difficult to make openings to lay or repair pipes, conduits, etc.; but this might be an advantage, if such a pavement would cause greater care in laying the pipes in the beginning.

1099. THE BLOCKS. The blocks should be made of sound and durable stone, free from seams, and should be of uniform hardness, since the pavement will wear unevenly if hard and soft blocks are laid together. For the appearance of the pavement, it is desirable that blocks of only one color be laid together.

Fig. 210 shows four stages in the manufacture of modern granite paving-blocks.

1100. Dressing. The blocks should be split and dressed so as to have as nearly as possible plane rectangular faces and square corners. The more regular the blocks the thinner the joints, and consequently the smoother and more durable the pavement. In a general way there may be said to be three standards in dressing stone paving-blocks.

1. Formerly the blocks were roughly dressed; and would lay with joints $\frac{3}{4}$ to 1 inch wide or perhaps more, and would show depressions of 1 inch under a 3-foot straight edge laid parallel to the curb. The joints were filled with pea gravel and sand or tar.

2. Recently there has been a demand for a less noisy and more sanitary pavement, and hence the blocks have been more accurately dressed, and the joints have been filled with bituminous cement and sand or portland-cement grout. In this case the blocks are dressed to conform to specifications about as follows: "The blocks shall be

FIG. 210.—FOUR VIEWS OF THE MANUFACTURE OF GRANITE PAVING-BLOCKS.

approximately rectangular on top and sides, and uniform in width. They shall be so cut that the joints between individual blocks when laid shall average not more than $\frac{3}{8}$ of an inch. The head of the block shall have no depression greater than $\frac{1}{4}$ inch from a straight edge laid in any direction and parallel to the general surface of the block."*

Fig. 211, page 576, shows the two types of pavements described above.

* Specifications, Borough of Manhattan, New York City, 1917.

3. It is very difficult to meet the above specification even when the best splitting granites are available, and it is practically impossible with the harder granites; and further, if the joints are filled with cement grout, there is little need to require joints as thin as

Old style in foreground; new style in background.

FIG. 211.—OLD AND NEW TYPES OF STONE BLOCK PAVEMENTS.

$\frac{3}{8}$ inch. Therefore some good authorities specify that the blocks shall be dressed so as to lay side joints not more than $\frac{3}{4}$ of an inch wide, end joints not more than $\frac{1}{2}$ inch, and that the top shall not depart more than $\frac{1}{4}$ of an inch from a true plane.

1101. *Re-cutting.* Formerly the blocks were made larger, especially deeper, than is now considered good practice; and besides the blocks were not dressed as accurately as is the custom at present. Consequently there are many stone-block pavements, particularly in the older cities, that are very rough and composed of comparatively large blocks; and hence in recent years many of these old blocks have been taken up, re-cut, and re-laid. Different methods are employed in breaking the old blocks depending upon their size. For example, blocks $12 \times 8 \times 4$ inches may be broken into four new ones $6 \times 4 \times 4$ inches. But blocks either much smaller or much larger receive different treatment. For example, with a smaller block, sometimes a new block is taken from the end, and two new ones are made from the remainder of the old block by dividing the depth; and for larger blocks sometimes four new blocks may be taken side by side successively from the end.* The blocks are

* For a liberally illustrated account of the method of re-cutting granite paving-blocks, see *Engineering News*, Vol. 73 (1915), p. 1020–23.

usually dressed to conform to the specifications in paragraph 2 or 3 of § 1100. The depth of the re-cut or napped blocks is usually less than that of the old ones; and therefore the re-cut blocks generally make a greater area of pavement than the original ones, the excess sometimes being nearly 100 per cent. The cost of taking up and re-cutting ranges from $\frac{1}{2}$ to $\frac{2}{3}$ of the cost of new blocks.*

1102. Size of Blocks. For an ideal pavement the blocks should be of one size; but if it were necessary to cut the blocks to exact dimension, the expense would be unreasonably great. It is considered good practice to allow variations in length from 8 to 12 inches, in width from $3\frac{1}{2}$ to $4\frac{1}{2}$ inches, and in depth from $4\frac{3}{4}$ to $5\frac{1}{4}$ inches. It is customary to require that the blocks shall be sorted according to width, and be laid in courses of practically uniform width.

The above specifications are for a block nominally 5 inches deep; but a few cities use blocks nominally 4 inches deep. When stone blocks were usually set in the native soil or in a thick sand cushion, it was customary to make the depth 7 or 8 inches; but when a concrete foundation was introduced, the depth was generally reduced to 5 inches. It is probable that with the more accurate cutting now customary, with a concrete base, a mortar cushion-coat and a grout joint-filler, a 4-inch granite block meeting the specifications of § 1100 will be more durable than either a 5-inch block with a sand cushion and a gravel filler, or a 7- or 8-inch block with a thick sand foundation and a gravel filler. The reduction of a block in depth by wear under the heaviest travel is inappreciable, particularly with a rigid filler. For information concerning the use of granite blocks less than 4 inches deep, see § 1117–18.

1103. Measuring. Usually the contractor buys the blocks by the thousand, but gets paid for them by the square yard; and therefore it is to his financial advantage to use as many large blocks as possible. Again, the man who sets the blocks is usually paid by the square yard; and therefore it is to his financial advantage to make the joints as wide as he may. It is very undesirable that it should be to the financial interests of the contractor and of the paver to secure a poor pavement, i. e., one having large blocks and wide joints. An excess in the width of the block is more important than in the length, since it is proportionally a larger matter, and also since it has a more important influence upon the quality of the pave-

* For an account of the history of re-cutting granite paving-blocks with examples of the saving in a number of cases, see Proc. Amer. Soc. Municipal Improvements, 1914, p. 321-35, and p. 336–42.

ment; and therefore special care should be taken to prevent either an excessive width of blocks or too thick side-joints. This precaution was more important formerly than at present, since then the joints were filled, or rather partially filled, with pebbles, and consequently wide joints were more destructive than now; but nevertheless the principle is still worth considering. To identify as far as possible the interests of the contractor with those of the city, the following method of measuring a stone-block pavement has been proposed.*

"The blocks must be substantially smooth and square on all their faces, and within the limits of the following dimensions: Not less than $3\frac{1}{2}$ inches nor more than $4\frac{1}{2}$ inches wide across their upper and lower faces; not less than 7 nor more than 8 inches deep; and not less than 8 nor more than 14 inches long, except where shorter stones are necessary to fill out courses.

"The sum to be paid per square yard shall be ascertained as follows: The number of blocks per square yard upon which the bid of the contractor is based shall be $22\frac{1}{2}$. The actual average number of blocks laid per square yard shall be determined as follows: The City Engineer shall from time to time, during the progress of the work, measure the width of 50 to 100 courses, and from this deduce the average width of a course. The average length of the blocks is hereby fixed for the purpose of computing the number of blocks laid per square yard, at $12\frac{1}{4}$ inches.†

"For each block or fractional part thereof, that the average number laid per square yard shall exceed $22\frac{1}{2}$, there shall be added to the contractor's bid per square yard an amount computed at the rate of $9\frac{1}{2}$ cents per block. For each block or fractional part thereof, that the average number laid per square yard shall fall short of $22\frac{1}{2}$, there shall be deducted from the contractor's bid per square yard an amount computed at the rate of $9\frac{1}{2}$ cents per block."

According to this method, if the contractor uses narrow blocks and thin joints, the price per squard yard is proportionally increased; but if he uses thick blocks and wide joints, the price per yard is decreased. To meet the case in which a contractor should buy large blocks at a considerable reduction, it might be wise to make the amount per block to be deducted greater than that added. For convenience in applying the above method, a table is computed which gives in one column the width of 50 courses and in a second column the corresponding number of blocks per square yard. Of course, the number of blocks to a square yard would vary with the specified dimensions of the blocks and with the width of joints,

* By Horace Andrews, City Engineer of Albany, N. Y., in 1890 in *Engineering Record*, Vol. 21, p. 314 and 329; Vol. 25, p. 110–11.

† This value was determined by measuring a number of blocks in pavements laid with blocks of the size stated above.

which latter would vary with the different kinds of stone and even with the same kind from different quarries, and could be determined in any particular case only by measuring the combined width of a number of courses of blocks in the pavement. The normal or contract number of blocks per square yard should be stated according to the quality of work desired.

Some cities buy the blocks and contract for laying them, a method which eliminates the interest of the contractor in using large blocks. In some cities it is the custom for the contractor to buy the blocks by the square yard in the pavement, in which case the contractor pays only for the blocks accepted, and has no financial interest in the size of the blocks or the thickness of the joints. In Great Britain it is customary to buy the blocks by weight, a method which eliminates any interest of the contractor in the size of the blocks.

1104. Some cities require the blocks to be inspected and sorted to sizes before being piled on the street. The advantages of this are: (1) After being stacked upon the street it is nearly impossible to inspect them, since only the outside blocks of the pile can be seen; (2) when the blocks are being laid, the inspector has enough to do to watch the quality of the workmanship without having also to inspect the blocks; (3) removing rejected blocks from the pavement delays the opening of the street; and (4) if the blocks are sorted before being piled upon the street, different sizes are not so likely to get into the same course, and therefore the joints will be narrower.

In Cleveland, Ohio, where the specified width of the stone paving-block was from $3\frac{1}{2}$ to 5 inches, the blocks were sorted into three classes. Class No. 1 included blocks from $3\frac{1}{4}$ to $3\frac{1}{2}$ inches, Class No. 2 blocks from $3\frac{3}{4}$ to $4\frac{1}{4}$ inches, and Class No. 3 blocks from $4\frac{1}{2}$ to 5 inches. Blocks in Class No. 1 were marked with red paint, blocks in Class No. 2 with blue paint, and those in Class No. 3 with black paint, so that when the blocks were delivered on the street each class could be easily recognized and laid by itself.

1105. SETTING THE BLOCKS. In placing the blocks, the workman should stand upon the finished work, that the sand cushion may not be disturbed; but he usually stands on the sand cushion, the blocks being piled on the sand bed behind him. The workman with the pointed end of the hammer shown in Fig. 212 excavates a hole, if need be, into which to set the block.

FIG. 212.—STONE PAVER'S HAMMER.

To secure the proper form to the surface of the pavement, a

chalk line is made upon each curb or a string is stretched in each gutter to indicate the top of the blocks, and a row of blocks 20 to 25 feet apart is set in the center of the street with their tops to grade as determined by measuring down from a string stretched from curb to curb. If the street is wide, one or more rows of blocks are placed between the curb and the crown. Ordinarily the surface of the pavement is brought to grade between the guide blocks with the unaided eye; but in the best work, a straight edge or string is placed parallel to the line of the street on the guide blocks, by which to grade the surface, and between these lines the blocks are brought to the surface indicated by a straight edge parallel to the line of the street resting upon the pavement already completed.

The blocks should be set with their long dimension across the street, except at street intersections; and should be placed in straight rows with as close joints as possible. Each course should be formed of blocks of uniform width and depth; and the bond should be approximately half the length of a blocks or at least 3 inches. As the blocks are of uneven lengths, the securing of the proper bond requires careful attention. The paver is instructed to secure thin joints, and consequently has a tendency to set the block with the larger end up; but when set in this way the block will surely sink under traffic. Placing the large end of the block down makes a wide joint, which is objectionable if the joints are to be filled only with sand and pebbles (§ 1108), but is no serious objection if the joints are to be filled with hydraulic-cement grout (see § 1112).

The courses at street intersections are arranged substantially as in brick pavements (§ 988). The work should progress up grade and from the gutter towards the crown, so that the blocks may have no tendency to settle away from each other and thus increase the width of the joints.

Fig. 213 shows four views of the laying of stone-block paving.

1106. RAMMING THE BLOCKS. After the blocks have been placed, they should be thoroughly rammed until they come to a firm bearing. As a rule the workman is more interested in securing a uniform surface than in bringing the blocks to an unyielding bearing. Each block should receive at least three hard blows—one near each end and one in the middle. The rammer employed, Fig. 214, page 582, weighs from 50 to 90 lb., ordinarily 60 to 75 lb.

If, after being rammed, a block does not conform to the general surface of the pavement, it should be lifted out, and sand should be added to the sand bed or extracted from it to bring the top of the

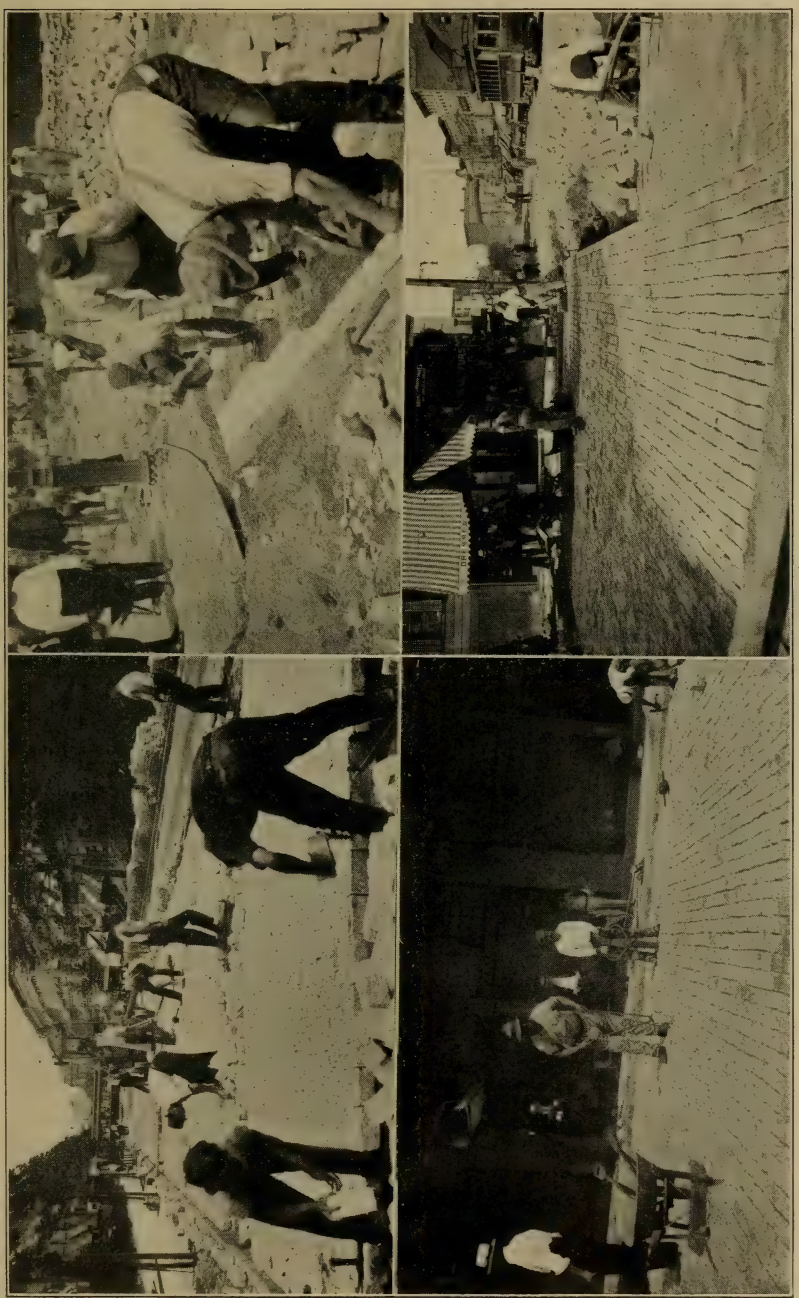


FIG. 213.—LAYING STONE-BLOCK PAVEMENT.

block to the proper elevation. Any imperfect or broken blocks should be removed and be replaced with perfect ones. Finally each block should be adjusted so that it stands perpendicular to the sand bed and has its top face conforming to the surface of the pavement. The quality of the pavement depends largely upon the care with which this adjustment is made.

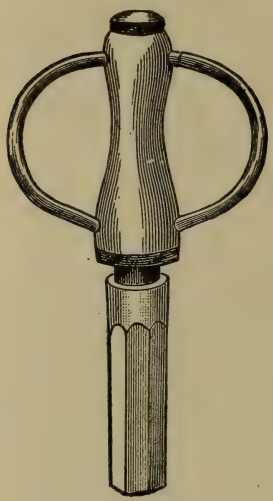


FIG. 214.—STONE-BLOCK RAMMER.

The ramming is likely to be slighted unless closely watched. The man who does the ramming is likely to tap lightly a block which if thoroughly rammed would be driven below the general surface of the pavement; and subsequent travel will force the stone down and make a depression in the surface. The important thing is to have each block equally and sufficiently rammed to bring it to a solid bearing on the bedding course and at the same time bring its top to the proper elevation.

To secure a thorough ramming of the pavement, it is sometimes specified that there shall be one rammer to each paver, and occasionally one rammer to two pavers. No ramming should be allowed within 20 or 25 feet of the course last laid, to prevent the tipping of the block out of the vertical position; but all the blocks set should be rammed before work ceases for the day.

Fig. 215 is a near view of a granite-block pavement.

1107. FILLING THE JOINTS. Four materials are in common use for filling the joints of stone-block pavements, viz.: (1) pea gravel, (2) tar and sand, (3) asphalt and sand, and (4) cement grout. The first is used with joints that are $\frac{3}{4}$ to 1 inch wide, and the others with joints $\frac{3}{8}$ to $\frac{3}{4}$ of an inch wide.

1108. Pea Gravel. Where the joints are $\frac{3}{4}$ to 1 inch wide, it is customary to fill them with pea gravel or pea gravel and tar. It is usually specified that the pea gravel shall pass a $\frac{1}{2}$-inch mesh and be retained on a $\frac{1}{4}$-inch mesh. If tar is to be poured upon the pebbles, they should not be too small, or they will not permit the tar to flow freely to the bottom of the joint. Since the joints are wide and the blocks are roughly cut, the joints are usually partly filled (say, $1\frac{1}{2}$ to 2 inches deep) with pebbles before the blocks are rammed, to keep them in place during ramming. After the joints have been

partially filled and the blocks have been rammed, the pebbles in the joints are tamped with a bar having a chisel-shaped end. The joints are next swept full of hot pebbles and again tamped.

1109. There are two methods in more or less common use for completing the filling of the joints.

1. The filling is completed by spreading fine sand over the pavement to a depth of $\frac{1}{2}$ to 1 inch, and allowing travel to work it into the

Joints in foreground not filled; joints in background filled with tar.

FIG. 215.—NEAR VIEW OF GRANITE-BLOCK PAVING.

joints. Until recently this was the only method employed, and even yet it is quite common. When filled in this way, the joints are not impervious; and the filling does not aid much in keeping the blocks in position.

2. Recently it has become the custom with the better class of stone-block paving to complete the filling of the joints by pouring hot tar over the pebbles. The tar is applied in substantially the same way as in the case of brick pavements—see § 1011–12. The

pebbles should be perfectly dry, for an almost inappreciable amount of water will cause the tar to foam and will prevent it from adhering to the pebbles and from forming a water-tight joint. It may be necessary to dry the pebbles artificially. The tar must not be applied when the pebbles are very cold. The joints should be entirely filled with the tar, to secure which it is usually necessary to pour the joints twice. To keep the contractor from having a financial interest in not filling the joints entirely full, it is sometimes specified that there shall be brought upon the ground not less than a stated number of gallons of paving cement for each square yard of pavement, and that whatever remains after the completion of the work is the property of the city.

In some cases it is specified that the pebbles and tar shall be applied alternately in three stages.

The quantity of tar required to fill the joints varies from 1 to $3\frac{1}{2}$ gallons per square yard, according to the width of the joints, which varies with the quality of the stone and the workmanship.

The tar in the joints makes the pavement impervious, and therefore more sanitary. The tar also assists in keeping the blocks in position, and therefore adds to the durability and smoothness of the pavement.

Fig. 216 shows the process of filling the joints of a stone-block pavement with tar. Incidentally this figure also shows the difference between the new and old types of pavements.

1110. Tar and Sand. When the joints are nominally $\frac{3}{8}$ of an inch wide, they are often filled with tar and sand, which is sometimes called tar-pitch mastic or pitch-sand mastic. The following are the specifications for this form of joint filler adopted by the American Society of Municipal Improvements.*

"The joint filler shall be the paving pitch hereafter described [see § 576–77], thoroughly mixed with as much hot dry sand as the pitch will carry; but in no case shall the volume of the sand exceed the volume of the pitch. The sand shall be fine and clean, and all of it shall pass a 20-mesh screen. It shall be heated to a temperature of not less than 300 nor more than 400° F.; and shall be between these limits when mixed with the paving pitch.

"The paving pitch shall be heated in kettles properly equipped with an approved thermometer, which shall register the temperature of the pitch.

"The mixture shall be flushed on the surface of the blocks and pushed into the joints with suitable tools, re-flushing or re-pouring, if necessary, until the joints remain permanently filled flush with the surface of the pavement. As little as possible of the mixture shall be left on the surface.

*Specifications for Stone-block Paving, as revised in 1916.

"In applying the filler care should be taken that the pavers are closely followed by the filler gang, and in no case shall the paving be left over night, or when work is stopped, without the filling of the joints being completed. In case rain stops the filler gang before its work is finished, the joints should be protected by the use of tarpaulins or other means, to keep out water. Under no circumstances shall the filler be poured into wet joints."

The tar pitch should comply with the specifications in § 576–77, except that northern cities, or rather cities that are subject to cool

Modern pavement in foreground; old-style pavement in background.

FIG. 216.—FILLING THE JOINTS WITH TAR.

weather the greater part of the year, should use pitch having a melting point from 115 to 125° F., and cities which have long-continued hot weather should specify a melting point from 125 to 135° F.

1111. Asphalt and Sand. The following are the specifications for this form of filler adopted by the American Society of Municipal Improvements.*

"The joint filler used shall be the asphalt cement hereafter described [see § 544], thoroughly mixed with as much hot, dry sand as the cement will carry; but in no case shall the volume of the sand exceed the volume of the cement. The sand shall be fine and clean and all of it shall pass a 20-mesh screen. The

* Specifications for Stone-block Paving, as revised in 1916.

sand shall be heated to a temperature of not less than 300 nor more than 400° F.; and shall be between these limits when mixed with the asphalt cement.

"The asphalt cement shall be heated in kettles properly equipped with an approved thermometer, which shall register the temperature of the cement.

"The mixture shall be flushed on the surface of the blocks and pushed into the joints with suitable tools, re-flushing or re-pouring, if necessary, until the joints remain permanently filled flush with the surface of the pavement. As little as possible of the mixture shall be left on the surface."

The specifications for the asphalt cement referred to above are given in § 544, page 282.

1112. Cement Grout. To secure the smoothest and most durable stone-block pavement, the joints should be filled with portland-cement grout, which should be mixed and applied as described in

FIG. 217.—GRANITE-BLOCK PAVEMENT EIGHT YEARS OLD.

§ 996–1005. However, since larger quantities are required for stone blocks than for bricks, it is usual to permit the grout to be mixed in a batch machine-mixer.

Fig. 217 shows a grout-filled granite-block pavement at Lowell, Mass., eight years old.

The portland-cement grout makes the joint impervious, holds the

blocks firmly in position, prevents the edges from chipping and the top face from wearing round, and adds materially to the smoothness and durability of the pavement.

1113. Expansion Joints. If the joints are filled with portland-cement grout, an expansion joint of $\frac{3}{4}$ to 1 inch in width should be provided next to each curb, constructed as described in § 1017; and expansion joints should be provided around manhole covers, water boxes, etc., as described in § 1021.

If the joints are filled with pebbles or bituminous cement, no longitudinal expansion joints are necessary.

Transverse expansion joints should not be provided, as they are not needed and are a decided detriment (see § 1018–20).

1114. Paving Adjacent to Track. Fig. 218 shows the standard method employed by the Paving Commission of Baltimore in laying granite-block pavement next to street-car rails.*

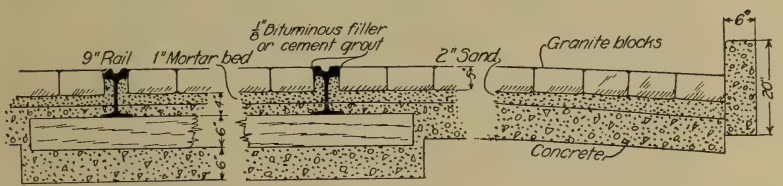


Fig. 218.—Granite-block Paving Adjacent to Track, Baltimore.

Granite blocks are much used for paving the railway area, because of their durability. When granite blocks are laid in the narrow strip between the rail and some other form of paving, they should be laid as stretchers or as headers, i. e., without toothing.

In Worcester, Mass., an expansion joint is constructed between the pavement on the track area and that on the remainder of the street. The joint extends through the wearing coat and the concrete foundation. The joint in the block course is made by nailing a pre-moulded mastic strip (§ 1017) against the ends of the ties. The joint is to prevent the rumbling of the grout-filled pavement due to the passage of a street car; and is effective.†

1115. Maximum Grade. Stone-block pavements are freely employed upon grades up to 10 per cent; and if the stone is a quality that does not wear smooth, they may be used upon grades up to 15 per cent.

**Engineering News*, Vol. 73 (1915), p. 884.
† *Ibid.*, *News*, Vol. 74 (1915), p. 398.

It has been recommended that on steep grades to afford a good foothold for the horses, (1) the edges of the blocks be chamfered, (2) that the joints be comparatively wide, and (3) that the joints be filled to within about an inch of the top with cement mortar. It is not known that these expedients have ever been employed; but the probabilities are that wide joints would be equally as effective without chamfering the blocks, since the edges spall off soon when the joints are wide and are filled with either gravel or tar. Further, the accumulation of dirt in the wide joints would probably largely neutralize their effect. Fig. 219 shows another method that has been proposed, but it is not known that it has ever been tried.

1116. MERITS AND DEFECTS. The only merit claimed for stone-block, particularly granite-block, pavement is durability. The material of the blocks does not decay or wear entirely out. But if the joints are filled with gravel or a soft filler, the face of the blocks wear round; and if a thick sand cushion is used, some blocks settle more than others. The result is that such a pavement becomes excessively rough and noisy; and if the granite is hard, the pavement is slippery.

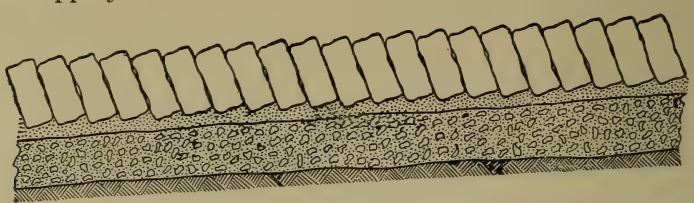


FIG. 219.—STONE-BLOCK PAVEMENT ON STEEP GRADE.

However, if the blocks are carefully dressed, are of nearly uniform size, and laid with thin joints; and if they are laid in a mortar bedding course and the joints are filled with portland-cement grout, the pavement is very durable and not specially noisy. A granite-block pavement is the form universally chosen where there are many heavily laden steel-tired wagons and trucks.

1117. DURAX PAVEMENT. This is a pavement made of cubes of granite placed upon a concrete foundation. In America and England it is known as durax pavement, and in Germany as kleinpflaster. This pavement has been used in Europe since about 1885, but the first in this country was laid in the Brooklyn Navy Yard in 1913. Since then it has been laid in a number of American cities.

The blocks are approximately cubes having faces $2\frac{1}{2}$ to $3\frac{1}{2}$ inches square. They are usually cut to lay approximately $\frac{1}{2}$-inch joints.

The cubes are generally machine made, and can be turned out cheaper per square yard than large hand-made ones; but on the other hand, they are not usually as accurately cut as the best large blocks. However, since the durax blocks are nominally cubical, they may be laid on any one of three sides, which gives a little advantage in fitting them into place. The blocks may be laid with any form of bedding course (§ 1095–98), or with any joint filler (§ 1107–12); but apparently they are usually laid on a 1-inch sand cushion, and with asphalt filler.

The blocks are not usually laid in straight course, but in concentric segments of circles, in what is sometimes called the oyster-shell

FIG. 220.—LAYING A DURAX PAVEMENT.

pattern. Fig. 220 shows the process of laying a durax pavement; and Fig. 221, page 590, is a close view of such a pavement.*

The advantages claimed for the segmental form of courses are: 1. There are only a few joints parallel to the direction of travel, and hence the stones wear better than in the ordinary oblong block pavement. This would not be important, if a grout filler is used. 2. Since there are no continuous transverse joints, opposite wheels of a vehicle can not drop into a joint at the same time; and hence there is less jar and less wear on pavement and vehicle. This would not be an important advantage, if the joints are filled with portland-cement grout. 3. Since the courses need not be kept straight, the blocks can be turned so as to give the narrowest joints. This may be an advantage in placing some of the blocks; but it is a disadvantage in

* *Engineering News*, Vol. 72 (1914), p. 529.

making closures between different segments. On the whole, the joints can not be as narrow as with large blocks equally accurately cut.

1118. The first cost of the blocks for durax pavement is less per square yard than for an ordinary granite-block pavement; but the labor of laying is much greater, and the total cost of the small-cube

FIG. 221.—OYSTER-SHELL PATTERN OF DURAX PAVEMENT.

pavement is more than that of the large-block pavement. The small cubes have been used to re-surface old macadam or other pavements. One advantage of the small cubes is that they may be made of the same thickness as a brick or asphalt or wood-block pavement, and hence a durax surface may replace the old one without disturbing the old foundation or changing the grade of the pavement. It is said that durax pavements are not now being laid in Europe to any considerable extent, and that the area of durax pavements in Europe is only about 3 per cent of that of oblong blocks.

1119. Cost. Price of Blocks. The following is the market quotation for stone paving-blocks for November 1, 1917.*

New York City, Manhattan,	standard granite	$2.50	sq. yd.
other boroughs	standard granite	2.25	"
other boroughs	5-inch granite	2.55	"
Boston	standard granite	2.55	"
Chicago, ordinary dressing,	standard granite	1.80	"
best dressing	standard granite	2.25	"
St. Paul	standard sandstone	1.65	"
Kansas City	standard limestone	2.15	"

The variation in price is partly due to the difference in freight and in price of labor, but chiefly to the ease with which the available material may be dressed. For example, according to data published by the U. S. Geological Survey, the average price of granite paving blocks per thousand in 1916 varied from $32 in California and $33 in Georgia to $62 in Minnesota and $66 in Wisconsin, the first two having easily worked granites and the last two granites difficult to work. Ordinarily, to lay a square yard of pavement requires 28 to 31 blocks.

1120. Granite-block Pavement. *New York.* In New York City in 1917 the cost of standard granite-block pavement is as follows:

Items.		Cost per Sq. Yd.
Concrete Base, 6 inches: materials and labor		$1.10
Sand Cushion, 1 inch: material and labor		.07
Wearing Coat:		
29 blocks at 9 cents on street	2.61	
labor laying	.22	
Total for wearing coat		$2.83
Joint Filling: 2 gallons of bituminous filler, sand, and labor of applying		.45
Total cost to contractor, exclusive of administration, tools, etc., and grading		$4.45

With a cement-grout filler in place of the bituminous filler, the cost is about 20 cents less, or $4.25 per square yard. With a cement-grout filler and a cement-mortar cushion, the cost is 5 to 10 cents per square yard less or $4.35 to $4.40 per square yard. In the Borough of Manhattan with the improved block there specified and with the difference in working conditions in that Borough, about 40 cents per square yard should be added, making the total cost about $4.85 per square yard.

**Engineering News-Record*, Vol. 79 (1917), Construction News, p. 179.

1121. *Chicago.* The average cost to the contractor of laying specially dressed granite blocks ($3\frac{1}{2}$ to 4 inches wide, 8 to 10 inches long, 5 inches deep, of which 28 to 31 lay a square yard) at Chicago in 1917, was about as follows:*

Items.		Cost per Sq. Yd.
Concrete Base: 6 inches: materials and labor		$0.92
Sand Cushion:		
2 inches of sand at $2.50 per cu. yd.	.13	
labor spreading	$.02\frac{3}{4}$	
Total cost sand cushion		$ .15$\frac{3}{4}$
Wearing Coat:		
granite blocks f.o.b. Chicago	$2.35	
hauling to street	.13	
carrying to paver	.06	
laying and ramming	.19	
Total for wearing coat		$2.73
Filling Joints:		
paving gravel at $2.00 per cu. yd.	$ .13	
labor spreading	.04	
tar at 9 cents per gallon	.10	
labor applying	.07	
Total for joint filler		$ .34
Total cost to contractor, exclusive of tools, administration, etc., and grading		4.14\frac{3}{4}$

Ordinary granite blocks cost 25 to 30 cents per square yard less than the special dressed blocks above, the cost of laying is 8 cents per square yard less, and the total of the other items is substantially as above, thus making the total cost of the ordinary granite-block pavement on concrete foundation about $3.75 per square yard.

1122. Removing, Re-cutting, and Re-laying. *Philadelphia.* The following data on the cost of removing, re-cutting, and re-laying granite-block pavement are from experience in Philadelphia.†

Removing old blocks	$0.035	per sq. yd.
Clipping the old blocks to $\frac{1}{2}$-inch joints	.50	" " "
Piling and inspecting new blocks	.07	" " "
Sand cushion	.08	" " "
Laying and grouting	.22	" " "
Gravel for filling joints	.04	" " "
Cost of grout	.09	" " "
Total	$1.035	" " "

*By courtesy of W. L. Weeden, Field Secretary of Granite Block Producers Association.

†W. H. Connell, Chief of Bureau of Highways (Streets), Philadelphia, in *Engineering and Contracting*, Vol. 40 (1913), p. 290.

1123. *Schenectady.* Table 65, page 594, shows the details of the cost of re-cutting and re-laying 2,578 square yards of granite blocks in Schenectady, N. Y.* The old blocks were 12 by 8 by 4 inches; and the new ones 6 by 4 by 4 inches, and were laid on a new 4-inch green concrete base with a thin bedding course of 1 : 3 dry cement mortar. The joints were filled with a 1 : 2 portland cement grout. The day was 8 hours. The work was done without interrupting travel.

1124. Durax. The following data are from experience in Louisville, Ky., in laying a small area of cubical granite blocks.† The blocks were $3\frac{1}{2}$ to 4 inches on a side, were made in North Carolina, cost $9.30 per ton f.o.b. Louisville, and were guaranteed to lay 7 square yards per ton, and consequently the guaranteed price was $1.33 per square yard, which was 67 cents per square yard less than standard-size blocks from the same quarry would have cost. A man laid 2.2 square yards per hour, whereas of standard blocks he would have laid 3.3 to 4 square yards per hour.

1125. Medina Block. *Buffalo.* For somewhat obvious reasons, the prices in 1917 were quite erratic, and hence it is not wise to cite them. Table 66, page 595, shows the representative cost of a Medina-sandstone block pavement in Buffalo, N. Y., in 1916.‡

1126. *Cleveland.* Table 67, page 596, shows the representative cost of Medina-sandstone pavements in Cleveland, Ohio, under a 5-year guarantee, in 1916.§

1127. *Rochester.* Table 68, page 597, shows the cost of Medina-sandstone pavements at Rochester, N. Y., in 1917.

1128. Cost of Grouting.|| *Lawrence.* The cost at Lawrence, Mass., of grouting standard granite blocks was as follows: Cement cost $1.08 per barrel, pea gravel $2.30 per cubic yard, sand $1.00 per cubic yard. To hold the blocks in place while being rammed, the joints were filled to a depth of 1 inch with pea gravel. The grout was mixed 1 : 1 in iron boxes (§ 997), and scooped onto the pavement and broomed. With wages at $2.25, the cost of applying the grout was 6.4 cents per square yard. The total cost of the grout in place was $26\frac{3}{4}$ cents per square yard.

1129. *Lowell.* At Lowell, Mass., grouting granite blocks on a

* Chas. A. Mullen, City Engineer, in *Municipal Engineering*, Vol. 46 (1914), p. 431.

† D. R. Lyman, Chief Engineer of Department of Engineering, in *Engineering News*, Vol. 72 (1914), p. 948.

‡ Frank L. Bapst, President German Rock Asphalt Co., which company lays much stone-block paving in Buffalo.

§ Robert Hoffman, Commissioner and Chief Engineer, Department of Public Works, Cleveland, O.

|| *Engineering and Contracting*, Vol. 44 (1915), p. 350–51.

TABLE 65

COST OF RE-CUTTING AND RE-LAYING GRANITE-BLOCK PAVEMENT

Schenectady, N. Y.

	Sq. Yd.
Taking up old pavement and preparing subgrade:	
Labor removing asphalt surface and concrete base, at $2.25 per day.	$0.0445
Team " " " " " " $5.00 per day.	.0156
Labor removing old granite blocks at $2.25 per day	.0305
" regulating and preparing subgrade at $2.25 per day	.0417
Team hauling materials from subgrade at $5.00 per day	.0241
Total	$0.1564
Concrete Foundation—1 : 3 : 6. 4 *inches thick:*	
Labor mixing and placing, at $2.25 per day	$0.1192
Cement, delivered ($1.24 per bbl. f.o.b. cars)	.1018
Sand, " ($0.25 per ton f.o.b. bank)	.0275
Stone, " ¾-inch at $1.30 per ton f.o.b. track " " 1½-inch at $1.75 per ton on job	.0835
Total	$0.3320
Bedding Course—1 : 3 *cement mortar:*	
Labor, mixing and placing, at $2.25 per day	$0.0738
Cement, delivered ($1.24 per bbl. f.o.b. cars)	.0868
Sand, " (25 cents per ton f.o.b. bank)	.0242
Total	$0.1848
Re-cutting and re-laying granite blocks:	
Labor breaking and dressing, at $5.00 per day	$0.7385
" sharpening and making tools	.0501
Materials for sharpening and dressing tools	.0058
Horse and wagon, moving blocks at $4.00 per day	.0059
Labor transporting blocks to pavers at $2.25 per day	.0396
" setting blocks, at $5.00 per day	.1796
" ramming blocks, at $2.25 per day	.0065
Total	$1.0260
Grout Filler—1 : 2 *portland cement:*	
Labor mixing and placing, at $2.25	$0.0466
Cement, delivered ($1.24 per bbl. f.o.b. cars)	.0707
Sand, " (25 cts. per ton f.o.b. bank)	.0106
Total	$0.1279
Over-head charges:	
Foreman at $4.00, assistant foreman at $3.50, etc	$0.0819
Watchman at $2.25	.0552
Total	$0.1371
Extras:	
Repairs to curbs, sidewalks, sewers, etc	$0.0430
Total cost of removing, re-cutting and re-laying	$2.0072

TABLE 66

COST OF MEDINA-BLOCK PAVEMENT IN BUFFALO IN 1916.

ITEMS.	Cost per Sq. Yd.
CONCRETE FOUNDATION, 1 : 8:	
cement at $2.00 per bbl., f.o.b. Buffalo	$0.37
sand crushed stone }	.32
mixing and laying, at 37½ cents per hour	.15
Total for concrete base	$0.84
SAND CUSHION: labor and material	$0.15
WEARING COAT:	
blocks f.o.b. quarry	$1.60
freight Medina to Buffalo	.18
unloading and hauling, at 75 cents per hour for team and driver	.20
labor laying blocks, at 60 cents per hour	.35
Total for wearing coat	$2.33
FILLING JOINTS:	
cement at $2.00 per bbl., f.o.b. Buffalo	$0.08
labor applying grout	.25
Total for filling joints	$0.33
MISCELLANEOUS:	
overhead expenses	$0.10
indemnity insurance at 3.17% of pay roll	.025
discount on City time warrants, 3%	.11
maintenance during 10-year guarantee period	.10
paid city for water	.02
Total miscellaneous	$0.355
Total cost of pavement exclusive of excavation	$4.005

2-inch sand cushion with 1 : 1 grout required 0.295 bag of cement per square yard; and the average cost was 24¼ cents per square yard.

1130. *Worcester.* At Worcester, Mass., a 1 : 1 grout required 0.36 cubic foot of cement per square yard; and the total cost of grouting was 24 cents per square yard.

1131. *Albany.* At Albany, N. Y., the cost of grouting standard granite blocks having side joints not exceeding ½ inch, using 1 : 1 grout mixed by machine, cost 13.9 cents per square yard. The cost of mixing by machine was 1.5 cents per square yard, and by hand 5.25 cents per square yard. The cement required was 0.4 bag per square yard.

1132. *Philadelphia.* At Philadelphia, Pa., when each standard block is "struck in" at the base to secure a close joint, and when 2 inches of pea gravel are deposited in the joints before ramming, a

TABLE 67

COST OF MEDINA-BLOCK PAVEMENT IN CLEVELAND IN 1916.

ITEMS.	Cost per Sq. Yd.
CONCRETE BASE, 6 inches of 1 : 3 : 6:	
materials and labor*	$0.98
SLAG CUSHION, 2 inches:	
material and labor spreading	.08
WEARING COAT, 6 to 6½ inches thick:	
stone blocks, f.o.b. quarry	1.65
freight Medina to Cleveland	.54
transporting from car to street, at 90 cents per hour for team	.10
laying	.45
Total for wearing coat	$2.74
TAR FILLER: material and labor	.35
FOREMAN: supervision	.02
Net cost to contractor	$4.17
OVERHEAD: administration, depreciation, interest, profits, etc.	.78
Price bid, exclusive of excavation	$4.95

Granite blocks cost $2.50 per square yard, f.o.b. cars Cleveland, which is 31 cents per square yard more than Medina blocks.

1 : 1½ grout required 0.27 bag of cement per square yard. The total cost of grouting, using mixing boxes (§ 997) and including contractor's profits, was from 17 to 20 cents per square yard.

1133. Cost of Tar-sand Filler. At Englewood, N. J., the total cost of applying a 1 : 1 tar-sand hand-mixed filler on standard blocks having ½-inch joints in which had previously been deposited "a small amount of grit," was as follows:†

Pitch,—1.7 gallons per square yard	$0.143	per sq. yd.
Labor handling the pitch	.02	" " "
Grit	.011	" " "
Sand	.019	" " "
Labor	.038	" " "
Total	$0.231	" " "

"Investigation showed that in every case the filler penetrated to the bottom of the block. It was also found that the volume of tar required to fill the joints was less than that smeared over the surface of the pavement in the two or three successive pourings."

* Sand $1.15 per ton f.o.b. cars Cleveland; broken stone $1.35 per ton f.o.b. cars. Loading and hauling sand and stone, 30 cents per ton per mile. Labor from 30 to 43 cents per hour.

† *Engineering and Contracting*, Vol. 47 (1917), p. 134.

TABLE 68

COST OF MEDINA-BLOCK PAVEMENTS IN ROCHESTER IN 1917 *

ITEMS.	Cost per Sq. Yd.
CONCRETE, 6 inches:	
materials and labor	$1.00
SAND CUSHION, 2 inches:	
sand at $1.50 per cu. yd. in place	.09
WEARING COURSE, 6 inches deep:	
blocks f.o.b. quarry	1.50
freight to Rochester	.07
loading and unloading	.03
hauling 1 mile	.05
distributing and sorting	.03
laying	.15
FILLING JOINTS:	
0.025 cu. yd. sand at $1.50	.04
1½ gallons of tar at 10 cents	.23
labor applying filler	.09
SUPERINTENDENCE:	
foreman at 40 cents per hour for 30 square yards	.015
Total cost to contractor exclusive of administration, tools, etc.	$3.29

1134. Contract Price. Table 69, page 598, shows the contract price of stone-block pavements in various cities, and incidentally gives considerable detailed information as to the practice in the several cities.

ART. 3. MAINTENANCE

1135. There are almost no data concerning either the method or the cost of maintaining granite-block pavements. Formerly, when the wide-joint and roughly dressed granite-block pavement was the only form, little or no attention was given to methods or cost of pavement maintenance, and this was particularly true of granite-block pavements. Since the introduction of the better dressed narrow-joint granite-blocks, there has not been time in which to develop a system of maintenance nor to determine the cost, particularly as a modern granite-block pavement is very durable and needs no repairs for the first few years.

* By courtesy of Walter L. Weeden, Secretary Granite Paving Block Manufacturers' Association.

TABLE 69

CONTRACT PRICE OF STONE-BLOCK PAVEMENTS IN VARIOUS CITIES *

Laid in 1912

Locality.		Amount Laid in 1912, sq. yd.	Concrete Base.		Kind of Filler.	Guarantee, years.	Total Thickness, inches.	Average Price[1] sq. yd.
State.	City.		Thickness, inches.	Proportions.				
California	Oakland	11 445	6	.....	grout	0	.....	$4.00[2]
	San Francisco	21 565	.....	.....	gravel	.....	7–9	3.50[2]
Connecticut	Ansonia	1 500	6	1 : 3 : 6	.....	.....	.....	2.10
Georgia	LaGrange	5 000	.....	.....	tar	0	10	1.75
Louisiana	New Orleans	4 119	6	1 : 3 : 6	grout	3	14	3.95
Maine	Portland	1 004	.....	.....	grout	.....	.....	2.30
Massachusetts	Lawrence	30 704	6	1 : 3 : 6	grout	0	7½	2.72
	Leominster	2 268	4	1 : 3 : 5	pitch	4	.....	2.47
	Lowell	22 418	6	1 : 4 : 11	[3]	.....	12	3.15
	New Bedford	12 310	4	Hassam	grout	.....	10	1.90[2]
	Westfield	6 197	4	1 : 3 : 6	.....	1	8½	3.30
Minnesota	Duluth	23 146[4]	5	1 : 3 : 6	grout	5	13	2.68[2]
	Minneapolis	7 900[4]	.....	.....	grout	.....	.....	2.75[4]
Missouri	Kansas City	13 248	6	1 : 3 : 6	grout	5	13	3.10
New Jersey	Newark	75 735	.....	.....	.....	5	.....	3.03
New York	Rochester	42 700	6	1 : 3 : 6	grout	5	13	3.18
	Troy	4 000	6	1 : 5	grout	5	.....	3.35
Oregon	Portland	3 914	6	1 : 3 : 6	grout	.....	12	3.45
Pennsylvania	Scranton	1 688	.....	.....	sand	5	9	2.10
	Wilkesbarre	2 156	6	1 : 2 : 5	grout	.....	12	2.70
Washington	Seattle	17 436	6	1 : 3 : 6	grout	.....	12	3.50
	Tacoma	11 002	6	1 : 3 : 6	grout	.....	11½	2.50
Wisconsin	Superior	10 078	5	1 : 3 : 5	.....	5	13	2.52
Canada	Montreal	48 000	6	1 : 3 : 6	.....	5	12	3.65
	Ottawa	10 041	6	1 : 3 : 6	grout	5	13	3.78
	Saskatoon	16 662	5	1 : 7½	grout	5	11	5.10
	Vancouver	55 359	6	1 : 2½ : 5	grout	5	13	4.50

[1] Including grading and concrete base. [2] Not including grading.
[3] Part grout and part pitch and tar. [4] Kettle River Sandstone.

1136. REPAIRS REQUIRED. The repairs ordinarily required are re-laying small areas, re-filling the joints, repairing spalling joints, raising low blocks, repairing where the foundation has settled, and re-laying over trenches or other openings.

1137. Re-laying. At present the most common work required in connection with the maintenance of stone-block pavements is taking up the old blocks, re-cutting, and re-laying them, which is a reconstruction rather than repair or maintenance; and usually the new pavement is of entirely a different type than the old. This subject has already been considered in § 1101.

* *Engineering and Contracting*, Vol. 39 (1913), p. 378–79.

1138. Re-filling Joints. If a bituminous filler is used, it may run out of the top of the joints, particularly near the crown, or be picked out by the traffic. When this occurs, the joints should be poured again. With dense traffic this may be required every two or three years. With a good portland-cement filler, the joints are not likely to need re-filling; but if it develops that in spots the filler was poor, the joints should be digged out and again filled.

1139. Spalling Joints. If pea gravel or sand is put into the joints, there is danger that the grout filler will fill only the top of the joint; and hence that the pressure due to expansion of the pavement, being concentrated near the top of the joint, will cause the edge of the block to spall. Usually there will be no spalling, if the grout penetrates 3 inches; but if the penetration is 1 inch or less, the blocks are likely to spall — generally the first summer after the pavement is completed, but sometimes not for two or three years, depending upon the time required for travel to fill the joints opened by the contraction of the pavement.

The spalling at joints can be prevented by clearing the joints of sand or gravel to a depth of 3 inches before applying the grout filler. If spalling occurs in the finished pavement, the blocks should be taken up, the joints cleaned, the blocks re-laid, and the joints re-filled.

In effect this is substantially the same defect as that of brick pavements described in § 1059.

1140. Raising Low Blocks. If a block was not properly bedded or sufficiently rammed, it may become depressed under travel, particularly with a thick sand bedding-course; and if so, it should be taken up, and re-laid. If a grout filler is used, it is practically impossible to remove a block without destroying it; and this is reason for special care in bedding and tamping blocks that are to be grouted.

1141. Settlement of Foundation. If there is a depression on the surface, it may be due to a settlement of the foundation and can be corrected substantially as described for brick pavements, see § 1056.

1142. Settlement of Trench. The effect and the remedy of the sinking of a stone-block pavement is the same as that of a brick pavement, see § 1057 and 1061.

1143. Cost of Repairs. There are almost no data on the cost of repairs for stone-block pavements, probably partly because of their long life and partly because only few repairs are ever made, the pave-

ments usually being allowed to continue in a bad state of repairs The only data on record seem to be cost of repairs in Buffalo, N. Y. (see § 868), where most of the stone-block pavements are Medina sandstone (§ 1086). In 1916 the annual cost of repairs on 218,090 square yards was 3.66 cents per square yard.*

*Report of Dept. of Pub. Wks.—Bureau of Engineering, 1915–16, p. 70.

CHAPTER XIX

WOOD-BLOCK PAVEMENTS

1144. Kinds of Pavements. There are two forms of wood-block pavements, viz.: the round-block and the rectangular-block.

1145. Round-block Pavement. Fig. 222 shows the usual form

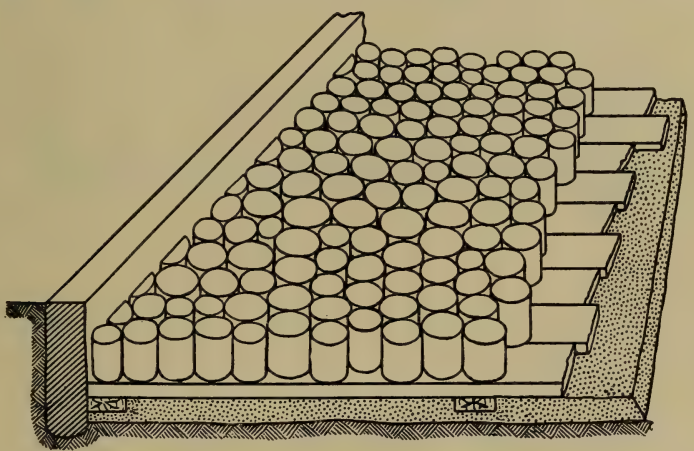


Fig. 222.—Round Wood-block Pavement.

of round wood-block pavement. This form is often called a cedar-block pavement, since the blocks are usually sections of cedar poles or trees. These blocks are generally placed on a foundation of planks nailed to scantling which are placed on, or rather in, sand.

Until about the close of the last century, untreated round wood-block pavements were laid in considerable quantities in localities where lumber was cheap; but now they are seldom laid, owing chiefly to the rapid increase in price of lumber and partly to the introduction of other cheap forms of pavements. Such pavements are laid now only where first-cost is the controlling factor, as for example, in new

city additions in states where the first pavement is selected and paid for by the owners of the abutting property, and the cost of maintenance and renewal is paid from the general property tax. In view of these facts, the round wood-block pavement will not be further considered in this volume.

1146. Rectangular-block Pavement. Fig. 223 shows the usual

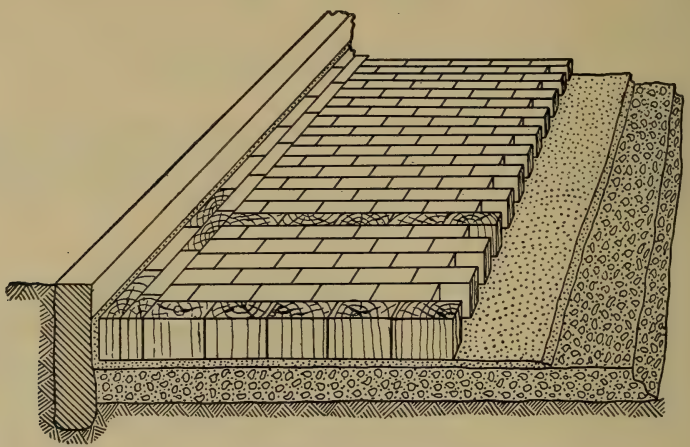


FIG. 223.—RECTANGULAR WOOD-BLOCK PAVEMENTS.

form of rectangular wood-block pavement. The rectangular block is usually treated with a preservative when used for paving purposes. This type of pavement will be considered in detail in this chapter.

1147. HISTORICAL. Wood appears to have been employed as a paving material first in Russia, where though rudely fashioned it has been used for some hundreds of years. Wood pavements were first laid in New York City in 1835–36, and in London in 1839.

The first wood used for pavements was untreated (§ 1145). The first pavement in this country made of treated blocks was laid in Galveston, Texas, in 1874; and remained in service for 29 years. A treated wood-block pavement was laid in St. Louis, Missouri, in 1882–85; and remained in use until worn out by the traffic. The first extensive use of treated blocks for pavements was in Indianapolis in 1896; and after 21 years these blocks are still in use and are said to be in a good state of preservation. Although a number of methods of preserving timber piles, railroad ties, etc., had been used in this country for several years, it was not until about 1900 that

there was any considerable use here of a preservative for wood paving-blocks.

1148. In 1909 $3\frac{1}{2}$ per cent of the pavements in the United States were wood-block (see table on page 320); but in 1900 such pavements constituted 10 per cent of the total (see a table similar to that on page 320, in the former edition of this volume). This seems to prove that the percentage of wood-block pavements is rapidly decreasing. However, the decrease is wholly in the untreated-block. The percentage of treated-block pavements is rapidly increasing, although it is still less than 1 per cent of the pavements included in the table on page 320.

ART. 1. MATERIALS AND TREATMENT

1150. THE TIMBER. Both hard and soft woods have been employed for making paving blocks. The hard woods were used untreated, and the soft varieties were treated. At present only treated timber is used; and of course the softer and cheaper woods are preferred, since they only can be impregnated with the preservative. Exceptions to the above statement are two Australian hard woods, jarrah and karri, that are much used in London without treatment.

1151. Jarrah and Karri. Jarrah is short grained and free splitting, and breaks with a clean fracture and burns with a black ash. In color it looks nearly like cherry. When seasoned, it has a specific gravity of 1.01 and absorbs about 10 per cent of water when immersed 48 hours.* Its transverse and crushing strength is about the same as that of English oak and Indian teak.

Karri is interlocked in the grain and is difficult to split; it splinters in breaking and burns with a white ash. It is a little lighter colored than cherry. When seasoned, it has a specific gravity of 1.12, and absorbs about 7 per cent of water when immersed 48 hours. Its transverse strength is a little greater than that of English oak or Indian teak, and its crushing strength is considerably greater.

For street paving, there is little difference between jarrah and karri, although for exceptionally heavy traffic karri shows slightly less wear. Karri shrinks less than jarrah. Both timbers are very plentiful in Western Australia, the trees growing with large, long straight bodies without limbs. Jarrah and karri are preferred in some vestries of London to any other form of wood paving-blocks.

* Most soft woods will absorb 20 to 25 per cent.

1152. Wood for Treated Blocks. The cost of lumber in the United States in the last few years, even before the Great European War, has been so great that the first cost of the blocks is an important consideration. Southern long-leaf yellow pine was almost exclusively used in early treated wood-block pavements; and is most largely used at the present time. It makes the most durable blocks of any timber yet tried. However, it is not entirely satisfactory, for the hardness which gives it durability against wear also makes it slippery; and further, it is liable to split when the blocks are taken up to repair underground work. Nevertheless, long-leaf yellow pine is the most satisfactory timber for treated wood-block pavements. However, as this timber is produced in only one section of the country the transportation charges are likely to be high, and besides the supply is nearly exhausted; and therefore where traffic conditions will permit, it is desirable to use a cheaper material.

Some years ago the U. S. Forestry Service, to obtain data as to the relative value of different species of wood for paving purposes, laid a great variety of woods under the same conditions on a street in Baltimore, Maryland, and conducted a similar experiment in Minneapolis, Minnesota. The conclusion reached as a result of the examination of the Baltimore experiment after four years of service, was that the different varieties could be grouped into classes in the order of the value for paving purposes as follows: (1) Southern long-leaf yellow pine; (2) Norway pine, white birch, tamarack, eastern hemlock; (3) Western larch; and (4) Douglas fir. The conclusion from the Minneapolis experiment after eight years of service was substantially the same.

The 1917 specifications of the American Wood Preservers' Association and also those of the American Society of Municipal Improvements call for Southern pine, which permits the use of either long-leaf or short-leaf Southern pine.

1153. Specifications for Blocks. *Dimensions.* The *width* was formerly 4 inches; but in recent practice it is sometimes 3 inches. The *length* varies widely so as to make available planks of different widths. The length specified is usually 5 or 6 inches to 10 inches; and often the average width is specified to prevent the use of too many short or too many long blocks. The average length is usually 6 or 8 inches. The *depth* must be enough to give the block stability,—say, 3 inches. This depth is used where the traffic is light; but under heavy traffic the depth is 4 inches, and in extreme cases $4\frac{1}{4}$ inches, as for pavements in the Borough of Manhattan, New York

City. If a 3-inch block is used its length should not exceed 8 inches.

While it is usual to specify that all the blocks for one job, or at least in any one city block, shall be of the same width, it is customary to permit a variation of $\frac{1}{8}$ inch in the width. A variation of $\frac{1}{16}$ inch in depth is generally permitted. Sometimes, to prevent a block from being laid on its side, it is specified that there shall be a difference between the width and depth of at least $\frac{1}{4}$ inch.

1154. *Quality of Blocks.* The blocks should be sawed square and true. They should be free from large, unsound, loose, or hollow knots; and should not contain any shakes, checks, or other defects. The blocks should be free from any blue tinge, which is a sign of incipient decay.

Specifications usually state the minimum number of annual rings permitted—some permitting 5 or 6 per linear inch, and others not less than 8 or 9. The amount of sap wood allowed varies from 10 to 40 per cent. In the early use of treated wood blocks, specifications were more rigid in limiting the amount of sap wood; but recent experience seems to indicate that there is no noticeable difference in wear between heart and sap wood.

1155. CAUSES OF DECAY. The decay of wood is due to a low form of plant life called fungi. Air, heat, and moisture are necessary for the existence of the fungous growth; and without any one of these the fungi can not live. Since air and heat are present in all climates, it is necessary to eliminate moisture to preserve the timber from decay. Seasoning, both air drying and kiln drying, is a method of removing part of the moisture, and hence is a method of preserving timber against decay; but any seasoned timber will re-absorb moisture, and hence seasoning is only an imperfect method of preservation. A more effective method is to inject into the timber some substance that will change the organic matter in the wood so it will no longer serve as food for the fungi.

1156. THE PRESERVATIVE. The preservative performs two functions, viz.: (1) acts as an antiseptic to prevent decay; and (2) acts as a waterproofing material to keep out moisture.

It is desirable that the preservative should be stable and remain in the block as long as possible; since where the travel is light, the life of the pavement depends upon the resistance of the blocks to decay. However, if an antiseptic has thoroughly penetrated the block, it will ordinarily be preserved against decay, even though a larger proportion of the preservative evaporates or is washed out.

But if the antiseptic evaporates or is washed out, the timber becomes again susceptible to changes in volume with changes of moisture content, which is objectionable in paving blocks.

Any material that renders a block waterproof is in itself a fair preservative, even though it is not an antiseptic. For example, petroleum is a fair preservative of timber, although it is not antiseptic. If water could be kept entirely out of the block, there would be little or no decay; but this is practically impossible, since no amount of preservative will make wood absolutely waterproof.

1157. Creosote is a distillate of coal tar, and is usually called creosote oil, and sometimes dead oil of tar. Creosote oil was the first material used for preserving paving blocks; and it is still the essential constituent in all such preservatives.

Creosote oil was not entirely satisfactory as a preservative for paving blocks. It preserved the wood and prevented decay; but it gradually evaporated and washed out, and permitted a change in the moisture content of the blocks, which caused expansion and contraction. To remove this objection, coal tar was added to the creosote to increase the waterproofing qualities of the preservative. The addition of tar also cheapens the preservative.

Coal tar may contain something like 40 per cent creosote oil, and hence is in itself a fair antiseptic; but on the other hand, it is harder to force the viscous tar into the wood than the more fluid creosote oil.

There is a considerable difference of opinion as to the relative merits of the different creosote preservatives. Some argue that the preservative should be pure creosote oil, having a specific gravity of 1.03 to 1.07, and a few claim that it should have a higher specific gravity but still be free from tar; while others prefer a mixture of creosoted oil and coal tar having a specific gravity of 1.08 to 1.12. Most cities now use an oil having a specific gravity of 1.10 to 1.14 and containing a large proportion of coal tar, which is usually required to be nearly free from carbon. The presence of any considerable amount of carbon is likely to plug the pores of the wood and prevent the introduction of the preservative.

Some engineers claim that water-gas tar (§ 564) gives satisfactory results, even though it has no antiseptic properties; but others claim that experience with this material has been too limited in both extent and time to warrant its use on a large scale. It is usually cheaper than a mixture of creosote oil and coal tar.

1158. Two proprietary methods of treating wood paving-blocks

were introduced comparatively early. One, called the kreodone process, consisted in impregnating block under pressure with a secret proprietary preservative. The other, called the creo-resinate process, consists in mixing melted resin and formaldehyde with the creosote, the resin being to waterproof the wood, and the formaldehyde is to increase the antiseptic effect of the preservative. This process was very efficient, but was discontinued on account of the increase in the cost of resin.

1159. Specifications for Preservatives. The specifications in § 1160, § 1161, and § 1162, were prepared by the American Wood-Preservers' Association,* and have virtually been approved by practically all of the national engineering societies interested in wood preservation.†

1160. *Creosote Oil.* Creosote oil was formerly used for railway ties, structural timber and wood paving-blocks; but lately, owing to its scarcity and cost, has not been used much, particularly for paving blocks. Paving blocks do not require as perfect a preservative as ties and structural timber, since usually their life is limited by their resistance to wear rather than to decay. Creosote oil when tested in accordance with the standard methods of the American Wood Preservers' Association, should comply with the following requirements:

"1. The oil shall be a distillate of coal-gas tar or coke-oven tar.

"2. It shall not contain more than 3 per cent of water.

"3. It shall not contain more than 0.5 per cent of matter insoluble in benzol.

"4. The specific gravity of the oil at 38° C. compared with water at 15.5° C. shall be not less than 1.03.

"5. The distillate, based on water-free oil, shall be within the following limits: up to 210° C. not more than 5 per cent; and up to 235° C. not more than 25 per cent.

"6. The specific gravity of the fraction between 235° and 315° C. shall not be less than 1.03 at 38° C., compared with water at 15.5° C. The specific gravity of the fraction between 315° and 355° C. shall be not less than 1.10 at 38° C., compared with water at 15.5° C.

"7. The residue above 355° C., if it exceeds 5 per cent, shall have a float-test of not more than 50 seconds at 70° C.

"8. The oil shall yield not more than 2 per cent coke residue."

1161. *Coal-tar Distillate Oil.* Coal-tar distillate oil for paving blocks, when tested in accordance with the standard methods of the

*Proceedings, 1917, p. 307–9.

†*Ibid.*, p. 41 and 325.

American Wood Preservers' Association,* shall comply with the following requirements:

"1. The oil shall be a distillate of coal-gas tar or coke-oven tar [§ 564].

"2. It shall not contain more than 3 per cent of water.

"3. It shall not contain more than 0.5 per cent of matter insoluble in benzol.

"4. The specific gravity of the oil at 38° C., compared with water at 15.5° C., shall be not less than 1.06.

"5. The distillate, based on water-free oil, shall be within the following limits: up to 210° C. not more than 5 per cent; and up to 235° C. not more than 15 per cent.

"6. The specific gravity of the fraction between 235° and 315° C. shall be not less than 1.03 at 38° C., compared with water at 15.5° C. The specific gravity of the fraction between 315° and 355° C. shall be not less than 1.10 at 38° C., compared with water at 15.5° C.

"7. The residue above 355° C., if it exceeds 10 per cent, shall have a float-test of not more than 50 seconds at 70° C.

"8. The oil shall yield not more than 2 per cent coke residue."

1162. *Coal-tar Paving Oil.* Coal-tar paving oil for paving blocks, when tested in accordance with the standard methods of the American Wood Preservers' Association,* shall comply with the following requirements:

"1. It shall be a coal-tar product of which at least 65 per cent shall be a distillate of coal-gas tar or coke-oven tar, and the remainder shall be refined or filtered coal-gas tar or coke-oven tar [§ 564].

"2. It shall not contain more than 3 per cent of water.

"3. It shall not contain more than 3 per cent of matter insoluble in benzol.

"4. The specific gravity of the oil at 38° C., compared with water at 15.5° C., shall be not less than 1.07 or more than 1.12.

"5. The distillate, based on water-free oil, shall be within the following limits: up to 210° C., not more than 5 per cent; and up to 235° C. not more than 25 per cent.

"6. The specific gravity of the fraction between 235° and 315° C. shall be not less than 1.03 at 38° C., compared with water at 15.5° C. The specific gravity of the fraction between 315° and 355° C. shall be not less than 1.10 at 38° C., compared with water at 15.5° C.

"7. The residue above 355° C., if it exceeds 35 per cent, shall have a float-test of not more than 80 seconds at 70° C.

"8. The oil shall yield not more than 10 per cent coke residue."

1163. *Water-Gas Tar.* Refined water-gas tar shall conform to the following requirements:†

"1. The specific gravity shall be not less than 1.12 nor more than 1.14 at 38° C., referred to water at the same temperature.

*Proceedings, 1917, p. 309–21.

†Specifications for Creosoted Wood-block Paving, American Society of Municipal Improvements, 1916, p. 5–6.

"2. Not more than 2.0 per cent shall be insoluble by hot extraction with benzol and chloroform.

"3. On distillation when made as hereinafter described,* the distillate, based on water-free oil, shall be within the following limits: up to 210° C., not more than 5.0 per cent; up to 235° C., not more than 15.0 per cent; up to 315° C., not more than 40.0 per cent; and up to 355° C. not less than 25.0 per cent.

"4. The specific gravity of the total distillate below 355° C. shall not be less than 1.0 at 38° C., referred to water at the same temperature.

"5. The oil shall not contain more than 2.0 per cent water; and due allowance shall be made for all water and insoluble foreign matter it may contain by injecting a corresponding additional quantity into the blocks."

1164. Treatment of Blocks. There are two methods of treating the blocks with the preservative, viz.: (1) the open-tank process, and (2) the pressure process.

1165. Open-tank Process. In this process the blocks are immersed in the preservative from a few minutes to an hour, depending upon the kind of wood and the degree of penetration desired. This method is largely used in France. In this country early in the history of treated paving blocks, it was much used; but it is not now used.

1166. Pressure Process. The standard specifications for the treatment of the timbers mentioned in § 1152, except Douglas fir, are substantially as follows:

"The blocks are placed in a closed cylinder, and subjected to steam at a temperature of 220° to 240° F. for not less than 2 hours nor more than 4 hours. The steam and moisture are blown out of the cylinder, and then the blocks are subjected to a vacuum of not less than 22 inches of mercury for at least 1 hour. While the vacuum is still on, the preservative, heated to a temperature of 180° to 220° F., is run in until the cylinder is completely filled, care being taken that no air is admitted. Pressure is then gradually applied at a rate not to exceed 50 lb. per square inch per hour, and is maintained at 100 to 150 lb. per square inch until the wood has absorbed the required amount of preservative. Next a supplemental vacuum of at least 20 inches is applied for at least 30 minutes. If desired this vacuum may be followed by a short steaming period.

"The timber may be either green or air seasoned; but should preferably be treated within three months after it is sawed. Green and seasoned timber shall not be treated together in the same charge.

"After treatment the blocks shall show a satisfactory penetration of the preservative; and in all cases the preservative must be diffused throughout the sap wood. The surface of the blocks after treatment shall be free from deposit of objectionable substances; and all blocks that have been materially warped, checked, or otherwise injured in the process of treatment shall be rejected."

* Accompanying the printed specifications, but not reproduced in this volume.

1167. The following are the reasons for the several steps in the treatment.

The preliminary steaming softens or liquefies the sap, so it may later be removed from the pores of the wood. The steaming also equalizes the moisture content of heart and sapwood, which equalizes the resistance to penetration, and thus prepares the wood to receive the preservative more uniformly. The preliminary steaming is applied whether the timber is green or seasoned. In green timber the sapwood contains more water than the heartwood; and unless the excess sap is removed, the blocks will contain untreated, or at least under-treated, sapwood. Therefore, green blocks should be subjected to steaming and the vacuum process to remove the excess water from the sapwood. On the other hand, seasoned timber is more easily treated, i. e., takes the preservative more easily, than green timber. Sometimes seasoned timber accepts the preservative so easily that almost no pressure is required to produce the desired absorption; and consequently the easily treated portion receives too much preservative and the portion that is more difficult to treat receives too little. The sapwood is likely to be more thoroughly seasoned than the heartwood; and therefore the former may receive more preservative than the latter, and consequently the latter may decay because of incomplete penetration of the preservative. The steaming of seasoned blocks expands them, so that when treated and laid in the pavement they will have a minimum expansion with the absorption of moisture. Therefore, seasoned timber should be subjected to steaming to prepare it to receive the preservative and to decrease expansion when laid in the pavement.

The preliminary vacuum is applied to remove the sap and moisture, which equalizes the resistance to the penetration of the preservative.

The preservative is applied under pressure and for a considerable time to secure complete penetration; but the pressure is applied slowly so as not to injure the strength of the wood.

The supplemental or final vacuum is applied to equalize the distribution of the preservative, but chiefly to remove the excess preservative in the outer portion of the block and thus decrease bleeding (§ 1211).

The final steaming is applied to soften and remove the excess preservative from the surface of blocks.

Finally, green and seasoned timber should not be treated together in the same charge, since they have unequal resistance to the penetration of the preservative.

1168. Amount of Preservative. The blocks laid in Indianapolis in 1896 (§ 1147) were treated by the open-tank process and contained only about 3 lb. of creosote oil per cubic foot. In the earlier applications of the pressure process, the amount was usually 10 to 12 lb. per cubic foot; but later the general practice was to inject from 20 to 24 lb. per cubic foot, which resulted in a greatly increased cost and an excessive bleeding of the blocks (§ 1211). Recently the tendency has been to reduce the absorption; and at present the average is about 16 lb. of water-free preservative per cubic foot. The standard specifications of the American Wood Preservers' Association and also those of the American Society of Municipal Improvements require 16 lb. per cubic foot.

The amount absorbed is determined from gages on the treating cylinder and a knowledge of the volume of the charge; and may be checked by weighing several blocks before and after treatment.

1169. Testing the Blocks after Treatment. Usually the only test made is to determine the penetration of the preservative. "To determine this, at least twenty-five blocks shall be selected from various parts of each charge, and sawn in half at right angles to the fibers, through the center; and if more than one of these blocks show untreated sapwood, the charge shall be retreated."

1170. Occasionally a test is made to determine the amount of water a treated block will absorb. The usual specifications for this test are: "The treated blocks after being dried in an oven at 100° F. for 24 hours, and then immersed in clear water for 24 hours, shall not absorb more than $3\frac{1}{2}$ per cent of their dry weight if pine, nor more than $4\frac{1}{2}$ per cent if tamarack." This test is to determine the possibility of the block's swelling after being laid, by the absorption of moisture; and therefore is quite important. The absorption will increase with the time after treatment; and therefore the blocks for this test should be taken from those about to be laid rather than from those recently treated.

The results by this test depend more upon the time since treatment and upon the method of storage than upon the method of treatment; and hence this is not an accurate test of absorbing power. Further, since no preservative process can make blocks absolutely waterproof, they should be so laid as to reduce to a minimum the amount of moisture absorbed (see § 1180).

1171. Care of Blocks after Treatment. The blocks should preferably be laid in the street as soon as possible after being treated. If they can not be laid within two days, provision should be made to

prevent them from drying out, by stacking in close piles and covering them; and if possible, sprinkling them thoroughly at intervals. To prevent expansion in the pavement through the absorption of water, the blocks should be well sprinkled about two days before being laid.

Art. 2. Construction

1173. Foundation. The subgrade should be prepared as described in Art. 1 of Chapter XV,—Pavement Foundations. The usual foundation is a layer of hydraulic concrete, which should be constructed as described in Art. 2 of Chapter XV.

The specifications of the American Society of Municipal Improvements state: "At no place shall the surface of the finished concrete vary more than a half inch from the given grade."

1174. Bedding Course. A bedding course is necessary to compensate for any unevenness in the top surface of the concrete foundation and to afford a good bearing for the blocks. Three forms of bedding course are in common use, which for brevity may be designated as sand, hydraulic-cement mortar, and bituminous cement.

1175. Sand Cushion. The sand bedding-course varies in thickness from 1 to 2 inches. The disadvantages of a thick sand cushion are very much the same for wood blocks as for brick—see § 977. In recent years, as in brick pavements, there has been a tendency to reduce the thickness of the sand cushion. The 1916 specifications of the American Society of Municipal Improvements require a cushion 1 inch thick, of "sand that will pass a $\frac{1}{4}$-inch screen and contain 10 to 25 per cent of loam or clay." The sand cushion should be struck with a template to a surface parallel to the grade and contour of the finished pavement; and should then be rolled.

Sometimes, instead of striking the sand cushion with a template, screeds are laid transversely across the pavement at intervals of 8 or 10 feet, being placed upon a ridge of sand or mortar so as to bring the top surface of the screed parallel to, and at the right distance below, the surface of the pavement. The sand is spread between the screeds, and then struck off to the right depth with a straight edge which rests upon the screeds and is kept parallel to the curb. This method requires more labor and does not give as accurate a surface as striking with a template. The only disadvantage of using a template is that a new one is required with each change in crown or width,

although this objection is overcome in part by using a template which is slightly adjustable.

1176. Substantially all of the comments concerning the sand cushion for brick pavements (§ 971–78) apply also to that for wood-block pavements. In addition, a sand cushion holds moisture, and hence increases the absorption of the blocks and adds to the troubles due to their expansion in the pavement. Formerly the sand cushion was the most common form of bedding course; but it has now practically been abandoned.

1177. Dry-mortar Bed. The method of laying wood blocks on a dry-mortar bed is substantially the same as for laying bricks on a cement-sand bedding course (see § 979–81). It would be possible to lay wood blocks upon a wet-mortar bed by either of the processes employed for brick pavements (see § 982); but it is not known that it has ever been done.

The 1916 specifications of the American Society of Municipal Improvements for preparing the dry-mortar bed for wood blocks are as follows:

"The concrete foundation shall be cleaned and swept; and shall be thoroughly dampened immediately in advance of the spreading of the cushion course. Upon the surface of the foundation thus prepared shall be spread a layer of mortar not exceeding ½ inch in thickness, made of one part portland cement and three parts of sand. Only sufficient water shall be added to this mixture to insure a proper setting of the cement, the intention being to produce a granular mixture which may be raked or struck by a template to the desired grade. The mortar shall be thoroughly mixed, and shall be spread in place upon the foundation by means of a template immediately in advance of the laying of the blocks."

1178. It is doubtful if the mixture of cement and sand ever gets enough water to cause it to set fully, since the joints between the blocks are quite narrow. The only reason for using a granular mixture is that it can be spread and struck easily; but the ordinary cement mortar containing enough water to insure a complete set, can be spread and struck without serious trouble. Or, better still, if the concrete foundation is finished with a slight excess of mortar on the surface, the wood blocks can be set in the mortar as are the brick in the monolithic brick pavement (§ 892).

An objection to the mortar bedding course is that the pavement can not be used until the mortar has set; but if the mortar bedding course is laid immediately after the concrete foundation is placed, this objection is eliminated.

A serious objection to the dry-mortar cushion is that not enough

water is used to secure a good quality of mortar. When the dry-mortar cushion is used for a brick pavement, the mortar is thoroughly wet by sprinkling the brick after they are laid; but this should not be done with wood blocks, since they absorb more water, and since with wood blocks the joints are usually filled with bituminous cement (§ 1187), which should be applied only when the blocks are dry.

1179. Bituminous Bed. If the top of the concrete foundation has not been finished to an accurate surface by strkiing with a template (§ 461–62), it should be leveled up by spreading a layer of 1 : 2

FIG. 224.—FINISHING MORTAR BEDDING-COURSE WITH A STEEL FLOAT.

cement mortar on it. This mortar should be of such consistency that it may be easily spread; and should be applied to the surface of the concrete before initial set of it has begun. The mortar should be then worked to an accurate surface by means of a long-handled wood float having upturned ends. When finished the surface should not show any depressions greater than $\frac{1}{4}$ inch under a 5-foot straight edge laid parallel to the curb. Fig. 224 shows the method of finishing the mortar bedding-course with steel floats; and Fig. 225 shows the method of finishing the bedding course with a wood-float.

1180. After the concrete base and the mortar coat have set and hardened, and after the surface has been thoroughly cleaned, and while it is perfectly dry, a coat of coal-tar pitch is spread upon the surface. The pitch should meet the specifications of § 576–77

(page 295) for filler for wood blocks; and should be applied at a temperature between 250° and 300° F. It should be spread to a uniform thickness of not more than $\frac{1}{8}$ inch, and be finished to a smooth surface. The blocks should be set directly upon this paint coat within 30 minutes after it has been applied. If the work is properly done, the blocks are firmly held in place; and in tearing up such a pavement it is not unusual to have the pitch pull up a film of the concrete base. If the surface of the concrete or the mortar coat has ridges or depressions in it, the blocks are likely to split under travel. If the pitch coat is thicker than $\frac{1}{8}$ inch, it is likely to flow

FIG. 225.—FINISHING MORTAR BEDDING-COURSE WITH A WOOD FLOAT.

and split the blocks. The slipping of the blocks on the pitch coat is sometimes called " floating."

The chief advantage of the bituminous bedding course is that the bituminous cement completely seals the pores of the block, and prevents the absorption of any water that may reach the top of the concrete base through cracks in the wearing coat. This method represents the best modern practice, and has recently been adopted quite generally.

1181. LAYING THE BLOCKS. Upon one of the three bedding courses described above, the blocks are set with the fiber vertical, in straight parallel courses, leaving a space at the curb 1 inch in width for the expansion joint. The blocks are laid " hand tight "; but each eight or ten courses are driven together by laying a 4- by

4-inch scantling against the last course and striking it with an axe or a sledge. No joint should be more than $\frac{1}{8}$ of an inch in width, although some good authorities permit a width of $\frac{3}{16}$ of an inch. The blocks should lap at least 2 or $2\frac{1}{2}$ inches. Only whole blocks should be used, except in starting and closing a course. The block used in starting or closing should have its cut face perpendicular to the top. In placing the blocks the workman should stand upon the blocks already placed, and never upon the bedding course.

There is no agreement as to whether the courses shall be perpendicular to the curb, or at an angle of 45° or $67\frac{1}{2}$°. It is claimed that if the courses are oblique to the curb, the wear at the joints, particularly the transverse ones, will be less than if the courses are perpendicular to the curb. But this claim has not been established; and as it is most convenient and costs about 2 cents per square yard less to lay the courses at right angles to the curb, this method has generally been adopted.

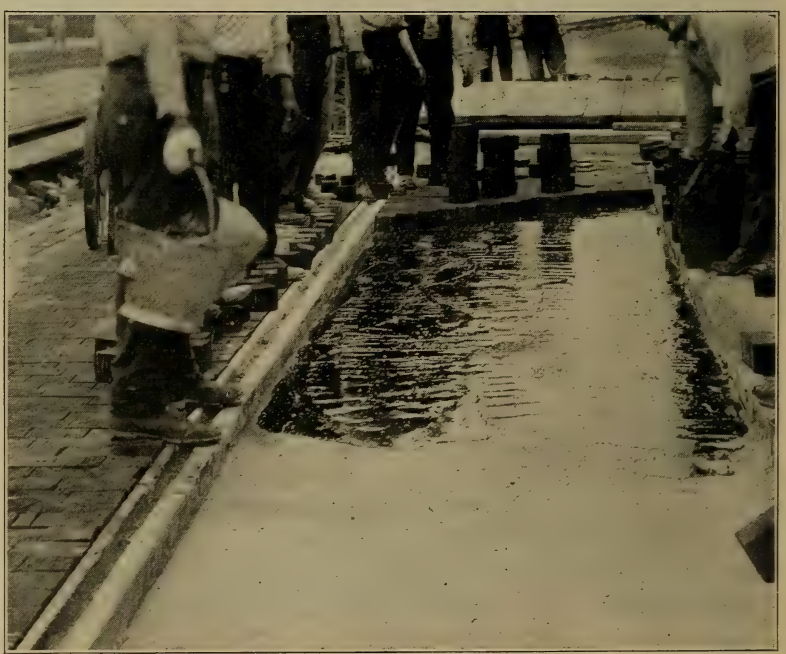


FIG. 226.—LAYING WOOD-BLOCK PAVEMENT BETWEEN STREET-CAR RAILS.

1182. Fig. 226 shows the method of laying wood blocks between the rails of a street-car track on a mop coat of tar over a smooth

concrete base. Fig. 227 shows the manner of laying wood blocks between the railway area and the curb. Note the plank next to the curb to provide space for the longitudinal expansion joint. The blocks are being laid on a mop coat of tar on a concrete base.

FIG. 227.—LAYING WOOD-BLOCKS ON A MOP COAT OF TAR.

1183. Rolling. After being placed, the blocks are inspected, and the rejected blocks are removed and replaced with acceptable ones. The surface should then be swept clean, and be rolled with a tandem roller weighing from 3 to 6 tons. The roller should begin at the side of the pavement, run slowly parallel to the center line, and work inwardly until the center of the road is reached. It should then move to the opposite side of the pavement and proceed as before. As the roller passes back and forth, it should overlap its course each time. After one rolling of the entire surface, the speed of the roller may be increased and the rolling continued until the blocks are thoroughly and evenly bedded.

Portions of the pavement inaccessible to the roller should be thoroughly rammed with a paver's rammer (§ 992) weighing not less than 50 lb., striking upon a plank not less than 6 feet long, 10 to 12 inches wide, and 2 inches thick. The plank should be laid parallel to the curb, and moved so that the surface will be equally rammed and brought to the proper elevation.

If the bedding course is green mortar, the rolling should be completed before the mortar has set.

When the rolling and ramming are completed, the surface of the pavement should conform so nearly to that indicated on the plans, that it will nowhere depart more than one fourth of an inch from properly formed templates or from a 10-foot straight edge applied parallel to the center line.

1184. JOINT FILLER. The joints between the blocks are filled with grout, sand, tar pitch, or asphalt.

1185. Grout. Occasionally the attempt is made to fill the joints of a wood-block pavement with hydraulic-cement grout; but if the blocks are set as closely together as they should be, the joints will be so narrow that it is impossible to get a good grout to fill them. If the grout is thin enough to flow into narrow joints, it will not contain enough cement to make it of much, if any, value; and besides it will not adhere well to the sides of treated wood-blocks, and even the preservative seems to kill the cement.

1186. Sand. Fine clean dry sand is swept into the joints; and the surface is covered with sand to the depth of $\frac{1}{2}$ an inch. The sand is placed upon the surface to insure that every joint is filled and to permit travel to grind the sand into the surface of the blocks. After the sand has remained on the pavement for a time, depending upon the density of the travel, it is swept up and hauled away.

Sand was formerly the most common joint filler, but it has practically been abandoned. It is cheap and makes a fairly watertight pavement; but it has little or no effect in binding the blocks together to prevent settlement due to shrinkage of the sand cushion (§ 1055) or other causes (§ 1056–57), or to prevent upheavals (§ 1060).

1187. Tar Pitch. The tar-pitch filler should conform to the specifications stated in § 576–77, page 295. It is heated in kettles or tanks on the street. The temperature should never exceed 325° F.; and it should be applied to the pavement at a temperature between 250 and 300° F. The hot pitch may be poured into the joints as described for brick pavements (see the second paragraph of § 1011). Fig. 228 shows a somewhat antiquated method of applying the filler to a wood-block pavement. This method is more suitable for a brick pavement than a wood one, since with the former the joint is wider, and hence it is easier to follow a joint with the point of the can; and also since more tar is required, and hence the tar flows better through the tip of the can.

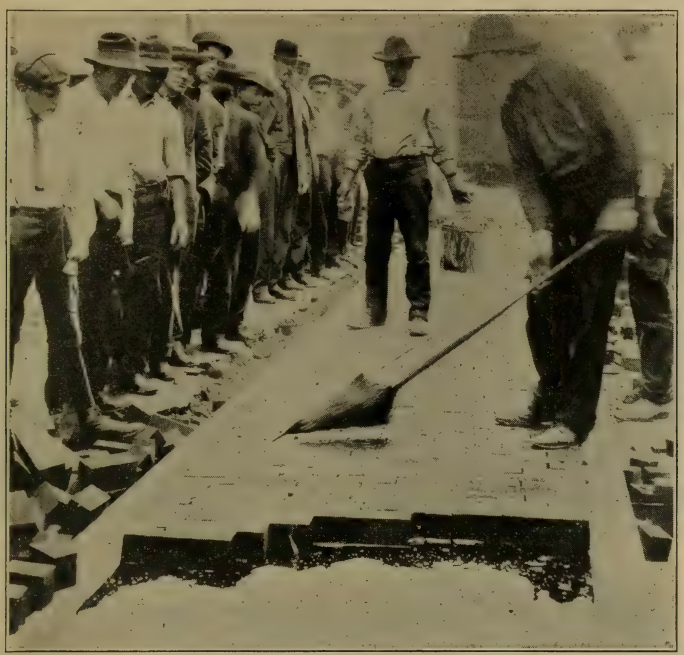


FIG. 228.—FILLING THE JOINTS WITH A CONICAL CAN.

Fig. 229 shows a better method of applying the tar joint-filler.

FIG. 229.—APPLYING TAR JOINT-FILLER WITH BUCKET AND SQUEEGEE.

Fig. 230 shows a buggy for transporting and applying pitch joint-filler.

FIG. 230.—BUGGY FOR APPLYING PITCH JOINT-FILLER.

Fig. 231 shows the finished wood-block pavement.

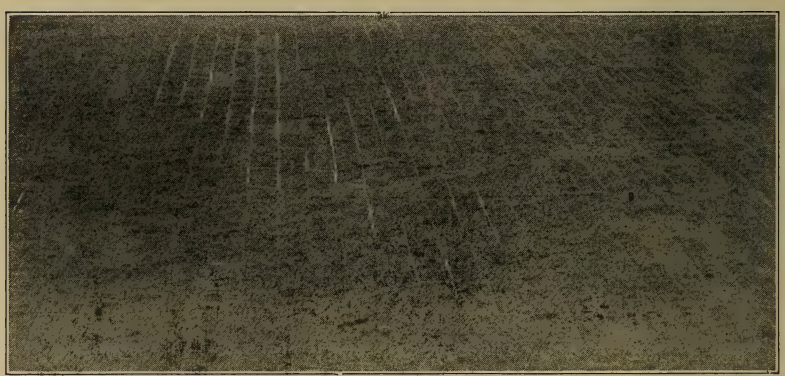


FIG. 231.—FINISHED WOOD-BLOCK PAVEMENT.

1188. In filling the joints care should be taken to leave as little bituminous cement on the surface as possible, since one of the objections to a treated wood-block pavement is that the preservative exudes, i. e., "the pavement bleeds," and covers the surface with a sticky mass (§ 211). If any joint filler is left upon the surface, it increases this objection. Further, some object to a bituminous filler, because it is liable to be forced out of the joints onto the surface of the

pavement. An advantage of a bituminous filler is that it virtually surrounds each block with an expansion joint, and hence decreases the expansion due to the absorption of moisture by the blocks.

Under no circumstances should the pitch be applied when there is any moisture in the joints; and therefore a pitch filler should not be used with a cement-sand bedding course (§ 1177).

1189. The specifications of the Ohio Department require that the lower half of the joints shall be filled with tar pitch as in § 1187, and the upper half with sand as in § 1186.

1190. Open-joint Construction. Since a wood-block pavement made as described above is quite smooth, it is customary to modify the construction on steep grades so as to give a good foothold to horses. Such construction is not employed unless the grade is more than 3 or 4 per cent—see Table 15, page 57.

Formerly a corner was cut out of the upper edge of a block as shown in Fig. 232 so as to give an open joint $\frac{1}{4}$ inch wide and

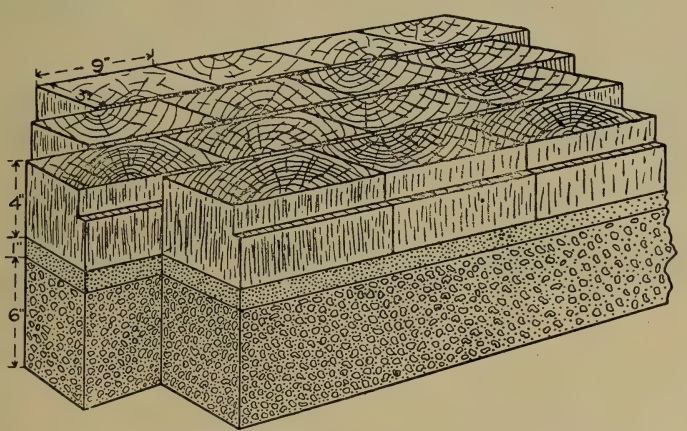


Fig. 232.—Rectangular Wood-block Pavement with Open Joints.

$1\frac{1}{2}$ inches deep; but at present it is more common and cheaper to place between adjacent courses a creosoted wood lath $\frac{5}{16}$ of an inch thick and 2 inches wide. The joint is poured about half full of bituminous filler; and then the space above the lath is filled with hot crushed stone, and the interstices between the stones are filled with bituminous cement.

Sometimes the upper edge of the face of the blocks is chamfered at an angle of about 45° to a depth of about $\frac{3}{8}$ of an inch; and this space is filled with the ordinary joint filler. This method is not as

satisfactory nor as cheap as the second one described in the preceding paragraph.

1191. Expansion Joints. The expansion of wood paving-blocks due to changes of temperature is not great enough to require any consideration; but the expansion and contraction due to change in the moisture content requires attention. The amount of expansion and contraction due to moisture depends somewhat upon the method of treatment. If the blocks are seasoned before being treated, and are not steamed before they are impregnated with the preservative, they are likely to absorb moisture and swell after the preservative has evaporated. Again, with green timber the steaming and the vacuum liquefies and removes the sap, and reduces the volume of the wood so it will be less likely to shrink when laid in the pavement. Finally, the amount of preservative should be such as to fill the cells of the wood and cover the fibers, thus making the blocks partially waterproof. An additional means of reducing the expansion and contraction due to moisture is to lay the blocks in a paint or mop coat of bituminous cement (see § 1179–80).

1192. To allow for expansion due to temperature and moisture, it is customary to construct a longitudinal expansion joint next to each curb. There are two forms of expansion joints, the poured and the pre-moulded.

The poured joint is made by placing a $\frac{3}{4}$ or a 1-inch board next to the curb, and setting the blocks against it (see Fig. 227, page 617); and after the blocks are set and the joints are filled, the board is removed and the space is filled with bituminous joint-filler poured hot (see Fig. 233). For an illustration of a brick pavement showing a thin board in place with wedges behind it to facilitate its removal, see Fig. 171, page 483.

The pre-moulded expansion joint is a sheet of felt or its equivalent saturated with tar pitch or asphalt. There are several somewhat similar forms on the market. For a few additional items concerning pre-moulded expansion joints, see the second paragraph of § 1017.

1193. Formerly transverse expansion joints were inserted in wood-block pavements; but they have been discontinued, because they are not needed, and are a positive detriment. The objections to the transverse expansion joint for wood-block pavements are substantially the same as for brick pavements—see § 1018.

Care should be taken to fill the joints around manholes, water-boxes, etc., to prevent water's reaching the foundation, where it will

freeze and lift the pavement, or be absorbed by the blocks and cause them to expand.

1194. CROWN. The surface of a wood-block pavement should be quite smooth; and therefore the crown should be comparatively small. A special committee of the American Society of Civil Engineers recommended that the transverse slope be between $\frac{1}{8}$ and $\frac{1}{4}$ of an inch per foot—see Table 16, page 65.

1195. MAXIMUM PERMISSIBLE GRADE. The maximum permissible grade for a close-joint wood-block pavement is 3 or 4 per cent (see Table 15, page 57); and with the open-joint construction (§ 1190), the maximum grade may be 6 or 7 per cent.

FIG. 233.—POURING THE LONGITUDINAL EXPANSION JOINT.

1196. PAVING ADJACENT TO TRACK. Wood-blocks are laid adjacent to the rails of street railway tracks in substantially the same manner as bricks—see Fig. 196 and 197, page 540.

1197. COST OF CONSTRUCTION. Price of Blocks. Table 70, page 624, shows the market quotation for treated wood paving-blocks for November 1, 1917. For more recent quotations, see construction news in current technical journals.

1198. Cost of Pavement. The following estimate was prepared for this volume by a specialist in wood preservation and wood paving who has no financial interest in contracting.†

1199. *Cost of Blocks.* Table 71, page 624, shows the amount of timber and preservative required. The method of using Table 71 in

† Mr. Walter Buehler, Mem. Amer. Soc. of Civil Engrs., Chicago.

TABLE 70

MARKET-PRICE FOR TREATED WOOD PAVING-BLOCKS*

LOCALITY.	ABSORPTION, lb. per cu. ft.	DEPTH, inches.	PRICE, per sq. yd.
New York City	16	3½	$2.00
" " "	16	4	2.25
Chicago	16	4	1.85
St. Louis	16	3½	1.80
" "	16	4	2.03
Kansas City	16	4	2.50
St. Paul	16	3½	2.00
San Francisco	16	3	2.15
" "	16	3½	2.26
" "	16	4	2.57
Seattle	16	4	2.35

TABLE 71

AMOUNT OF LUMBER AND PRESERVATIVE REQUIRED FOR PAVING BLOCKS

Depth of Block, Inches.	LUMBER REQUIRED, Feet, B.M., per Sq. Yd.			PRESERVATIVE REQUIRED, Gallons per Sq. Yd.		
				Absorption, Lb. per Cu. Ft.		
	Net.	Waste.	Total.	10	12	16
3	27	2.7	30	2.443	2.945	3.928
3½	31.5	3.15	35	2.862	3.546	4.583
4	36	3.6	40	3.274	3.928	5.238

determining the cost of blocks is as follows: Assume the cost of lumber at the treating plant at $30 per thousand feet, B. M., which under normal conditions prevailing a few years ago would not be over $25. Assume that the preservative meets the specifications of § 1161; and that it costs 9 cents per gallon. Assume that the blocks are to be 3½ inches deep, and are to be treated with 16 lb. per cubic foot. The cost of the blocks are:

Lumber 35 feet B.M., at $30	$1.05	per sq. yd.
Preservative 4.583 gallons at 9 cents	.414	" " "
Labor, depreciation, interest, etc	.240	" " "
Factory cost	$1.704	" " "
Profits at 15 per cent gross	.30	" " "
Factory selling price	$2.004	" " "

The approximate weight of wood blocks treated with 16 lb. per cubic foot is as follows: 3-inch, 130 lb. per square yard; 3½-inch 150 lb. per square yard; and 4-inch, 170 lb. per square yard.

* *Engineering News-Record*, Vol. 79 (1917), Construction News, p. 180.

1200. *Cost of Wearing Coat.* Table 72 shows in detail the estimated cost of a 3½-inch wood-block pavement with two forms of bedding course.

TABLE 72

ESTIMATED COST OF 3½-INCH WOOD-BLOCK PAVEMENT

ITEMS.	BEDDING COURSE.	
	Tar Paint Coat.	Dry Mortar.
Sub-grade, see Table 56, page 546	$0.217	$0.217
Concrete Foundation, see Table 56, page 546	.568	.568
extra finish to surface	.01	
Bedding Course, 1 : 4 dry cement and sand	.....	.18
0.5 gallon of pitch, and labor	.06	
Wood Blocks, see § 1199	2.004	2.004
freight, say, 200 miles at 6 cents per 100 blocks	.09	.09
hauling, at 60 cents per hour	.05	.05
laying, at 25 cents per hour	.08*	.08*
rolling	.01	.02
Joint Filler, including longitudinal expansion joint	.12	.12
Top Dressing, purchasing and spreading sand	.02	.02
Total cost, exclusive of interest, insurance, depreciation, profit, etc.	$3.229	$3.349

1201. Example of Cost. Table 73, page 626, shows the cost of laying 150,000 square yards of creosoted wood-block paving in Minneapolis by city force, and are given in unusual completeness, and hence are specially valuable in making estimates.

1202. The following are the details of the cost of laying a wood-block pavement in Cambridge, Mass., in 1913.† Common labor was 31 cents per hour. The foundation consisted of 5 inches of 1 : 2½ : 5 concrete; and the bedding course was 1 inch of cement and sand. The blocks were southern long-leaf yellow pine treated with 20 lb. of preservative. The joints were filled with 1 : 1 cement grout. Longitudinal expansion joints were provided at each curb, and transverse contraction joints at each 30 feet. 4-inch blocks cost $2.59 per square yard delivered on the street, and $4.11 per square yard complete in the pavement; and 3½-inch blocks cost $2.29 and $3.81, respectively.

1203. Contract Price. Table 74, page 627, shows the contract price of wood-block pavements in various cities, and incidentally also gives considerable information as to the details of practice of these cities.

*If there is a street-railway track, add 2 cents.

†*Engineering News*, Vol. 71 (1914), p. 1131.

TABLE 73

COST OF WOOD-BLOCK PAVEMENT IN MINNEAPOLIS*

ITEMS.	PER SQ. YD.
SUBGRADE: grading and shaping	$0.2 87
CONCRETE BASE, 1 : 3 : 6, 6 inches thick:	
cement, $1.12 per bbl., f.o.b. cars	.1222
sand $0.60 per cu. yd., delivered	.0395
stone, $1.00 per cu. yd., f.o.b. quarry, $1.70, delivered	.2386
labor mixing and placing by hand at 28 cents per hour	.1392
hauling cement, plank, etc., at 59 cents per hour	.0238
concreting strip 1½ ft. wide between railway ties	.0189
Total for concrete base	$0.5822
SAND CUSHION, 1 inch: sand at 60 cents per cubic yard on job	$0.200
WOOD BLOCKS, Norway pine and tamarack:	
4-inch, treated with 12 lb. of creodone creosote	1.3275
hauling blocks at 59 cents per hour	.0495
laying blocks at 22½° with curb, at 40 cents per hour	.0716
Total for blocks	$1.4486
JOINT FILLER, sand and pitch:	
sand at 60 cents per cu. yd., on job	.0055
pitch at 5.7 cents per gallon	.0490
labor at 28 cents per hour	.0175
Total for filler	$ .0720
HEADERS:	
4×10-inch plank at cross streets and alleys	.0030
MISCELLANEOUS:	
materials	.0077
labor	.0002
cleaning up	.0071
tools	.0200
Total miscellaneous	$ .0350
Total average cost	$2.3795

1204. MERITS AND DEFECTS. The merits of a treated wood-block pavement are: 1. It has a smooth surface, and therefore is a quiet pavement. It is less noisy than sheet asphalt, brick or stone-block; and from the standpoint of tenants, this is an important advantage. 2. It is a reasonably durable pavement, even under heavy and dense travel. This conclusion has been established in many cities in this country and in Europe. 3. The pavement is easy to clean; and its surface does not grind up and make dirt. 4. It has a low tractive resistance.

*B. H. Durham, Street Engineer, in *Engineering and Contracting*, Vol. 35, p. 451.

TABLE 74

CONTRACT PRICE OF WOOD-BLOCK PAVEMENTS IN VARIOUS CITIES*

Laid in 1912

LOCALITY.		Amount. Laid in 1912, Sq. Yd.	CONCRETE BASE.		Kind of Filler.	Guarantee, Years.	Total Thickness, Inches.	AVERAGE PRICE. Per Sq. Yd.[1]
State.	City.		Thickness, Inches.	Proportions.				
Connecticut...	Bridgeport...	10 000	6	1 : 3 : 6	sand	5		$3.10
	S. Norwalk...	3 400	5	1 : 3 : 5	sand	5	9½	3.19
Georgia.....	Albany.....	10 000	5	1 : 3 : 6	sand	.....	9	2.18
Illinois.....	Granite City.	10 000	6	1 : 3 : 5	pitch	.....	10½	2.54[2]
	Quincy.....	9 171	5	1 : 3 : 6	asphalt	5	9½	2.66
Iowa.....	Burlington...	22 000	6	1 : 3 : 6	asphalt	5	10½	2.77
Kentucky....	Louisville....	1 578	.....	.....	sand	5	.....	2.85[2]
Louisiana.....	New Orleans.	18 401	6	1 : 3 : 6	pitch	3	10	3.00[2]
	Shreveport...	54 000	5	1 : 3 : 5	sand	.....	8	2 24
Maine.....	Bangor.....	1 700	6	1 : 3 : 6	pitch	5	9½	3.88
Mass.....	Springfield...	12 949	.....	.....	.....	0	.....	3.13
Minnesota....	Hibbing.....	44 608	5	1 : 3 : 6	asphalt	5	9½	2.77
	Minneapolis..	130 000	.....	1 : 3 : 6	pitch	.....	.....	2.43
	Owatonna...	29 184[3]	5	1 : 8	pitch	5	9½	2.29[2]
	Virginia.....	22 854	6	1 : 2 : 4	pitch	5	10½	2.69[2]
Mississippi...	Greenwood...	25 000	6	1 : 3 : 5	bitu.	5	11	2.42[2]
Missouri.....	Kansas City..	1 021	6	1 : 3 : 6	sand	5	11	2.95
Montana.....	Miles City...	4 500[3]	5	1 : 6	asphalt	3	9	3.20[2]
New Jersey...	Jersey City...	11 891	5	1 : 3 : 5	sand	.....	9½	3.00
New York....	Plattsburg...	1 979	6	1 : 3 : 6	sand	3	10	3.08[3]
	Rochester....	8 392	6	1 : 3 : 6	sand	5	10½	3.32
S. Carolina...	Charleston...	9 000	4	1 : 3 : 5	.....	5	8	2.72[3]
Texas.....	Brownsville..	29 000	.....	.....	sand	.....	.....	2.70
Canada.....	Hamilton....	12 000[4]	6	1 : 3 : 6	.....	.....	10	2.85
	Vancouver...	189 875	6	1 : 2½ : 5	pitch	5	10½	3.20[2]

[1] Including grading and concrete base [2] Exclusive of grading. [3] 3-inch block [4] 20 lb. per cu. ft.

The defects of a treated wood-block pavement are: 1. It is somewhat slippery, particularly when its surface is moist. In this respect it is about on a par with sheet asphalt. 2. Its surface is liable in hot weather to become covered with a sticky mass which adheres to wheels of vehicles and tracks into houses (§ 1211). 3. It is rather high in first cost.

1205. SPECIFICATIONS. The American Society of Municipal Improvements in 1916 adopted complete specifications for Creosoted Wood-block Paving; and substantially the same specifications have been adopted by the American Wood Preservers' Association and

* *Engineering and Contracting*, Vol. 39 (1913), p. 380–81.

other associations interested in wood paving. Copies of these specifications may be had for a nominal sum of the secretary of the first-mentioned society.

Art. 3. Maintenance

1206. The experience with treated wood-block paving has been comparatively short, and hence there has not been developed any general method of maintenance or repairs.

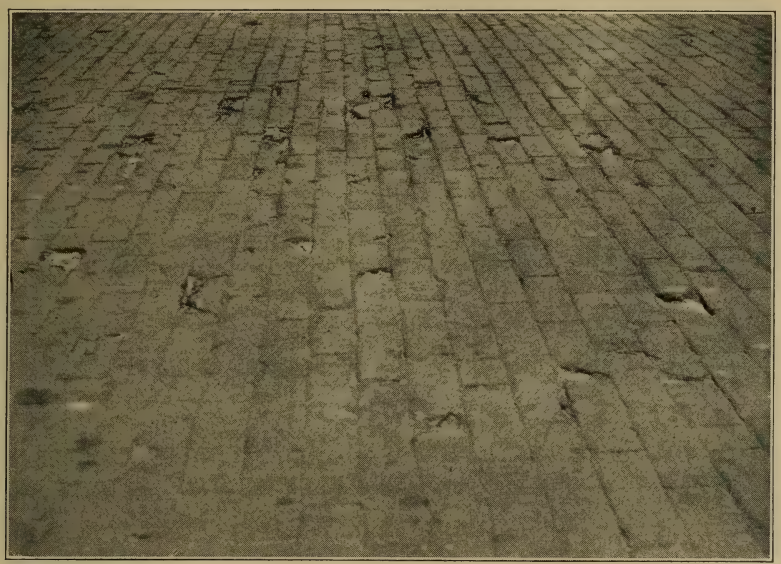
1207. Defects to be Removed. The principal matters requiring attention are: removing poor blocks, raising low spots, re-laying over trenches, lowering bulges, removing exudation.

1208. Removing Poor Blocks. Blocks fail owing to defects in the timber or to imperfect treatment. The latter do not usually appear until after the pavement is several years old. Generally, only a portion of a single block fails, and usually only a few blocks in each city block. Fig. 234 shows the failure of a single block;

Fig. 234.—Failure of a Block on Westminster Place, St. Louis.

and Fig. 235 shows the failure of several blocks. Not infrequently the failing blocks are in a bunch, indicating that there was probably something wrong with a single charge. The failure or decay is ordinarily due to insufficient preservative in either the sap-

wood or the heartwood (see § 1167). At first the hole is small and shallow, and does no great harm, although it gradually enlarges, particularly if there is much heavy steel-tired traffic. The defect can be temporarily cured by filling the hole with bituminous joint-filler



Treated in 1903. Photographed in 1915.

FIG. 235.—FAILURE OF SEVERAL BLOCKS ON WESTMINSTER PLACE, ST. LOUIS.

or better with mortar or fine concrete made with bituminous cement. The only permanent remedy is to cut out the defective block and replace it with a good one, which can be done easily and quickly. With a little care and attention a new block can be inserted so that the patch is hardly visible.

1209. Raising Low Spots. Frequently shallow depressions appear in the pavement. These holes may be due to the settlement of the foundation (§ 1056), to the settlement of the soil in a trench (§ 1057), or to the shrinkage or shifting of the sand cushion (§ 1055). Such holes are objectionable because they are unsightly, particularly when filled with water; and they hold water which dissolves the preservative, and also causes the blocks to swell and perhaps buckle. The sinking of the blocks break the bond of the joint filler, particularly if it is not bituminous; and may permit water to reach the foundation, which if it freezes may lift the pavement. The remedy is to take up the spot, remove the cause and re-lay the blocks. For a

discussion of precautions to be taken in re-laying a brick pavement under similar conditions, many of which are equally applicable in re-laying wood-block pavements, see § 1061.

1210. Re-laying over Trenches. It is frequently necessary to re-lay a wood-block pavement over a trench on account of the settlement of the soil in the trench or because a trench is opened to repair or lay a pipe or sewer. For a discussion of the method of re-laying a brick pavement over a trench, see § 1061.

1211. Lowering Bulges. A bulge or ridge is sometimes formed in a wood-block pavement by the expansion due to the absorption of moisture. If the pavem entis not provided with adequate longitudinal expansion joints, the bulge may be longitudinally along the crown of the pavement; or a bulge may take place at a raised footway crossing or at the crown of an intersection pavement (see § 1060). Usually a bulge can be replaced by removing a few blocks along the crest of the bulge, pressing the adjoining pavement back to place, and re-laying the blocks that were removed.

1212. Bleeding. In some cases the preservative fluid oozes out of the blocks and forms a thick sticky mass on the surface of the pavement, which is picked up by the wheels of passing vehicles and is tracked into houses. When this occurs the pavement is said to bleed. The bleeding may be due to one or more of the following causes, viz.: 1. The expansion by heat of the air in the pores of the block may force out the preservative. 2. The absorption of moisture by one part of a block or one portion of the pavement may cause an expansion which forces the preservative out at some other point. 3. Too much preservative may have been injected.

Steaming and the vacuum treatment of green blocks decreases the bleeding by removing the air from the cells and by reducing the absorption of preservative in the sapwood; and the steaming of seasoned blocks reduces bleeding by expanding the blocks to their maximum size so that when laid they will be less likely to expand by the absorption of moisture. The bleeding occurs only in hot weather. The character of the preservative makes little or no difference in the amount of bleeding, many claims to the contrary notwithstanding. Apparently a pavement bleeds less under heavy than under light travel, partly because the traffic seals the pores of the wood and prevents the oil from escaping, and partly because passing wheels carry away the sticky materials as rapidly as it oozes out.

1213. The remedy for a bleeding pavement is to sprinkle it with fine dry sand, and remove the sand after it has absorbed the bitumi-

nous material. In extreme cases it may be necessary to apply a second coat of sand. Usually the worst cases do not bleed after the first year or two.

1214. Cost of Maintenance. There is an unfortunate dearth of data concerning the cost of repairs or of maintenance of any pavement; but the lack is greater for treated wood-block pavements than for any other kind, since the experience with such pavements is comparatively limited (§ 1147), and since most such pavements have been laid under a 5-year guarantee.

The following examples are from a report by George W. Tillson, Engineer of the Borough of Brooklyn, New York City, presented at the Third International Road Congress in London in 1913.*

Wood-blocks treated by the creo-resinate process (§ 1158) were laid on Tremont Street, Boston, in 1900; and after the pavement "had been in use 12 years it had cost absolutely nothing for repairs, and was said to be in such a condition that it would probably remain intact for 10 years longer. It is stated by the engineer in charge of the Boston pavements that the same is true of 14,000 square yards laid at about the same time and in the same way."

"In the Borough of Brooklyn, the first creosoted wood pavement was laid in 1902, without any guarantee, and has cost absolutely nothing for repairs. Pavements that were laid later and have been out of guarantee from 3 to 4 years, have been kept in repair by the Borough; and an accurate record kept of their cost. Some of these pavements have cost absolutely nothing, and the average cost for the entire area out of guarantee has been 1.05 cents per square yard per year. Many of these pavements, however, have been opened for sub-surface work; and the engineer in charge of pavements states that in his opinion practically all of the repairs are due to settlements over trenches and damage caused by fires, and not to actual wear and tear of traffic."

"The Borough of Manhattan has three streets which have been out of guarantee three years, one of heavy traffic, one of medium traffic, and one of light traffic. The heavy traffic street has cost 7 cents per square yard per year, while the average of all has been 6 cents per square yard per year. But the repairs have been due to wear and tear only on the heavy traffic street, which is a wholesale street in the business section. Repairs on the other streets are due to settlements over trenches, and damage caused by fire; and practically nothing to wear and tear of traffic."

* *Engineering and Contracting*, Vol. 40 (1913), p. 7–9.

"The City of Minneapolis, Minn., has 1,000,000 square yards of wood-block pavements, the first of which was laid in 1902. The City Engineer states that these pavements have required practically no repairs, the cost in 1911 being less than $\frac{1}{10}$ cent per square yard. He also states (in 1913) that the street paved in 1902 is in good condition, and looks as if it might last for 10 years longer."

"In St. Louis, Mo., in 1909, the repairs to 50,000 square yards of wood pavement laid in 1903 cost $2.10; and in 1911 these same 50,000 square yards cost less than $\frac{2}{10}$ cent per square yard, so that the total cost of repairing the 50,000 square yards of wood pavement the first nine years they were laid was $\frac{2}{10}$ cent per square yard. These pavements are all on light traffic streets."

CHAPTER XX

SELECTING THE BEST PAVEMENT

1217. Kinds of Pavements. Pavements have been constructed of a variety of materials; but the forms discussed in the preceding chapters—hydraulic concrete, bituminous concrete, asphalt, brick, stone block, and wood block—are the only ones of importance now constructed; and it is improbable that any other paving material of value will be introduced. From time to time notices appear in the general newspapers of the introduction of some new pavement. Among the new paving materials of which somewhat laudatory notices have appeared are compressed hay, devitrified glass, cork, and rubber. All such novelties are either an attempt of an eccentric inventor to sell his goods, or a construction to meet limited and peculiar conditions. For example, it has been stated that rubber has been tried as a paving material in London; but the facts are that it has been used only to the extent of 300 or 400 square feet in a hotel porte cochère.

1218. Table 75, page 634, shows the number of miles and the percentages of the different kinds of pavements in the 158 cities having a population of over 30,000 in 1909. These data are the same as those in the table on page 320.

It is interesting to note that (1) practically one half of all the pavements in Table 75 are in the 16 cities having a population of 300,000 or over; (2) two thirds of the asphalt pavements are in cities having a population of 300,000 or over, and that one third of this amount is in New York City; (3) New York City, Indianapolis and Minneapolis have more than one half of the creosoted wood-block pavements; and (4) nearly one half of the water-bound macadam is in cities having a population of over 300,000.

Table 76, page 635, shows the percentages of the different kinds of pavements for three different dates in the larger cities of the United States. These data are interesting as showing the progressive

TABLE 75

PERCENTAGES OF DIFFERENT KINDS OF PAVEMENTS*

In 1909 in cities having a population of 30,000 or over

Ref. No.	Kinds of Pavement.	Length, Miles.	Per Cent.
1	Asphalt-sheet	4 293	20.4
2	block	261	1.2
3	Bitulithic	192	0.9
4	Brick	2 807	13.4
5	Cobble stone	536[1]	2.6
6	Concrete—portland cement	25	0.1
7	Gravel—water-bound	2 556	12.2
8	bituminous-bound	274	1.3
9	Macadam—water-bound	6 325	30.1
10	tar-bound	142	00.7
11	portland-cement grouted	16	0.08
12	Stone block	2 596	12.4
13	Wood block—creosoted	156	0.7
14	untreated	614[2]	2.9
15	Other kinds	211	1.0
	Total	21 004	100.0

[1] Nearly half in Baltimore. [2] More than half in Chicago.

changes in the percentages of the different forms of pavements. For example, note the increase in the percentage of asphalt pavements, and the decrease in cobble-stone. Notice that no brick pavements were reported separately in 1890. It is interesting to note that the percentages of water-bound macadam and stone-block pavements, the extremes as to durability, remained nearly stationary. The increase in the total number of miles of pavements, is shown below.

YEAR.	NUMBER OF CITIES.	CITIES HAVING POPULATION OF OVER.	TOTAL MILES OF PAVEMENT.
1890	262	10 000	12 453
1901	135	30 000	15 099
1909	158	30 000	21 004

Doubtless if Table 76 were brought up to date, there would be some material changes. For example, cobble-stone pavements would practically disappear, portland-cement concrete would greatly increase, bituminous concrete (other than bitulithic) would appear in the list, a considerable proportion of the water-bound gravel and macadam pavements would change to bituminous bound, and untreated wood block would nearly disappear.

* Compiled from "General Statistics of Cities for 1909," Bureau of Census, Washington, D. C., 1913, p. 154–59.

TABLE 76

PERCENTAGES OF DIFFERENT KINDS OF PAVEMENTS AT DIFFERENT DATES

Ref. No.	Kind of Pavement.	PERCENTAGES IN		
		1890[1]	1901[2]	1909[3]
1	Asphalt-sheet	3.2	13.6	21.6
2	block			
3	Bitulithic	.....	.....	0.9
4	Brick	.....	7.9	13.4
5	Cobble-stone	15.1	6.8	2.6
6	Concrete—portland cement	.....	.....	0.1
7	Gravel—water-bound	31.0	14.7	12.2
8	bituminous-bound	.....	.....	1.3
9	Macadam—water-bound	27.0	30.6	30.1
10	tar-bound	.....	.....	0.7
11	portland-cement grouted	.....	.....	0.08
12	Stone block	12.1	13.4	12.4
13	Wood-block—creosoted	.....	.....	0.7
14	untreated	7.8	8.7	2.9
15	Other kinds	2.9	4.3	1.0
	Total	100.0	100.0	100.0

[1] Compiled from "Social Statistics of Cities, Eleventh U. S. Census, 1890," p. 15–16.

[2] Compiled from "Statistics of Cities, Bull. No. 36, U. S. Dept. of Labor, Sept., 1910," p. 876–79.

[3] Compiled from "General Statistics of Cities for 1909," U. S. Bureau of Census, Washington, D. C., 1913, p. 154–55.

ART. 1. THE DATA FOR THE PROBLEM

1219. DURABILITY OF PAVEMENTS. The durability or life of a pavement is the most important factor in determining which is the best pavement. The durability of a perishable paving material, as untreated wood and to some extent macadam and asphalt, depends upon both the climate and the traffic; but in general the durability of paving materials depends chiefly upon the amount of the travel, and consequently the durability of different pavements can be accurately compared only when the nature and the amount of the travel over each is known. Unfortunately there are very little definite data as to the amount of travel upon American pavements. Not infrequently the travel on a particular pavement is referred to as being "heavy" or "light," but such general terms are practically worthless in comparing the durability of different kinds of pavements.

1220. Travel Census. Although data on the use made of pavements are of vital importance in attempting to compare the relative durability of different paving materials, comparatively few observations have been made concerning the travel upon American pave-

ments. For a discussion of the causes that have led to this surprising result, see § 640–42 (page 321–24). For a statement of the importance of a travel census in considering the cost of construction and maintaining a road or pavement, see § 29 (page 25). For a brief account of some observations made concerning the nature and amount of the travel on rural roads, see § 30–33 (page 26–28); and for a brief reference to the few censuses that have been taken of travel on American streets, see § 34 (page 28).

In some respects the most elaborate census of street travel taken in this country was that made by the Barber Asphalt Paving Company in 1885. Table 77, page 637, shows the results. It is not worth while to describe the methods employed in making the observations or in computing the results, since the data are very greatly out of date owing to radical changes in both the character and the amount of the travel. For example, in St. Louis from 1914 to 1915, the total travel on certain business streets increased 20 per cent, the motor-driven traffic increasing 53 per cent and the horse-drawn decreasing 15 per cent.* However, apparently the data in Table 77 are the most elaborate that have yet been published. Table 77 is instructive as showing the great variation in the travel on different streets of any particular city and also of different cities.

1221. Table 78, page 638, gives the travel record of certain streets in London and Liverpool. The marked difference in the travel on the pavements of London and on those of New York is due chiefly to the use of omnibuses in London and street cars in New York City. This example illustrates the importance of having definite data as to the amount of travel; and also shows the importance of taking account of local conditions in attempting to compare the results in one city with those in another.

1222. It is desirable that engineers in charge of streets should ascertain by direct observation the amount of tonnage passing over each pavement, in order that the service per unit of cost of different pavements may be accurately compared. The only measure of the durability of a pavement is the amount of travel tonnage it will bear before it becomes so worn that the cost of replacing it is less than the expense incurred by its use. It is also desirable that all such observations should be made in accordance with a standard plan, so the results from different cities will be comparable (see § 35–38).

1223. Elements Modifying Durability. Although the effect of

* *Engineering News*, Vol. 76, (1916), p. 832–34.

TABLE 77

TRAVEL ON CERTAIN STREETS IN VARIOUS AMERICAN CITIES IN 1885*

Ref. No.	Locality. City.	Locality. Street.	Width of Pavement, in Feet.	Number of Tons. Total per Day.	Number of Tons. Per Vehicle.	Number of Tons. Per Foot of Width per Day.
1	New York..	Broadway, near Pine.....	40	10 905	1.39	273
2	" " ...	Fifth Ave., opp. Worth Monum't.	40	3 744	.68	94
3	" " ...	Wall, corner of Broad.....	27	2 357	1.00	87
4	Philadelphia	Broad, in front of P.R.R. Station	65	9 237	1.52	142
5	"	Filbert, in front of City Hall....	65	6 302	1.24	97
6	"	Chestnut, corner of Fourth.....	26	1 928	1.06	74
7	Chicago....	Wabash, near Lake.....	50	7 561	2.08	151
8	"	Clark, near Madison.....	45	6 398	1.46	142
9	"	La Salle, near Locust.....	36	2 756	.90	77
10	"	Dearborn, opp. Washington P'k.	38	2 604	1.11	69
11	Boston.....	Devonshire, opp. Post Office....	27	5 301	.99	196
12	"	Devonshire, near Milk.....	32	5 028	1.02	157
13	"	Kilby, near State.....	26	3 265	.93	126
14	"	Washington.....	39	2 938	.80	75
15	"	Arch, near Summer.....	26	1 130	.79	43
16	"	Court Square.....	24	744	.67	32
17	St. Louis....	Locust, near Beaumont.....	36	3 691	1.13	103
18	" " ...	Broadway, near Olive.....	50	3 618	1.23	72
19	" " ...	Pine, near Garrison.....	36	2 554	1.16	70
20	" " ...	Chestnut, near Beaumont.....	36	942	.90	27
21	" " ...	Olive, near Beaumont.....	36	259	.84	7
22	New Orleans	Tchoupitoulas, near Poydras....	40	6 204	1.81	155
23	" "	St. Charles, near Washington...	30	1 065	.94	35
24	Washington.	15th, opposite Treasury.....	70	4 622	1.02	66
25	"	9th, between D and E.....	50	1 688	.87	34
26	"	7th, between D and E.....	50	1 455	.88	29
27	"	6th, between Pa. Ave. and B....	60	1 289	1.01	21
28	Buffalo.....	Main, near Swan.....	56	2 613	.83	47
29	"	Main, near Bouck Ave.....	42	1 505	1.88	36
30	"	Linwood, near Ferry.....	38	825	1.47	22
31	"	Main, near Glenwood.....	50	714	1.24	14
32	Louisville...	Main, near 3d.....	61	4 176	1.25	69
33	" ...	8th, near Walnut.....	36	2 402	1.05	67
34	" ...	7th, near Jefferson.....	35	977	1.05	28
35	Omaha.....	Douglass, near 15th.....	63	2 967	.62	47
36	"	Farnham, near 14th.....	60	1 449	.59	24

* Trans. Amer. Soc. of Civil Engrs., Vol. 15 (1886), p. 123–38.

TABLE 78

TRAVEL ON CERTAIN STREETS IN LONDON AND LIVERPOOL IN 1879*

Ref. No.	Locality.		Pavement.		Number of Tons.		
	City.	Street.	Kind.	Width in Feet.	Per Day.	Per Vehicle.	Per Foot of Width per Day.
1	London	Gracechurch	Asphalt	32	13 507	1.11	422
2	"	King William	Wood	40	16 484	1.06	412
3	"	Poultry	Asphalt	22	8 330	1.02	378
4	"	Strand and Fleet	Wood	37	13 596	.84	367
5	"	Parliament	Macadam	45	14 380	1.01	322
6	"	Oxford	Wood	57	17 076	1.01	300
7	"	Cheapside	Asphalt	32	9 260	.98	290
8	"	Leadenhall	"	30	7 588	1.08	253
9	"	Piccadilly	Macadam	37	9 358	.87	253
10	"	Euston	Granite	44	10 658	.88	242
11	"	Brompton	Wood	....	.....	.....	216
12	"	King William	Granite	32	6 506	1.02	203
13	"	Edgeware	"	43	8 376	1.02	195
14	"	Regent	Macadam	52	9 668	.90	186
15	"	King's	Wood	....	.....	.....	156
16	"	Victoria	Macadam	40	5 780	.96	145
17	"	Sloane	Wood	....	.....	.....	93
18	Liverpool	(Not named)	Granite	....	.....	.....	382
19	"	" "	"	....	.....	.....	232
20	"	Great Howard	Wood	....	.....	.....	231
21	"	Bold	"	....	.....	.....	100

travel is dependent chiefly upon the number of tons per foot of width, its influence is modified somewhat by (1) the character of the pavement, (2) the state of repairs, (3) the degree of cleanliness, (4) the presence or absence of car tracks, (5) the width of pavement, (6) the character of the travel, and (7) the climate.

1. The durability of a particular kind of pavement will vary with the details of the method of construction. The foundation may be more or less rigid, the materials may differ greatly in durability, with any form of block pavement the joints may be more or less open, and the surface may also vary more or less in roughness.

2. The durability will depend upon the care employed in repairing the pavement. If holes, depressions, or ruts are allowed to remain for any length of time, whatever the material the pavement will wear abnormally fast.

3. The degree of cleanness will materially modify the durability

* Trans. Amer. Soc. of Civil Eng'rs, Vol. 15, (1886), p. 131.

of a pavement. An imperishable material is benefited by a covering of detritus, since it serves as a carpet to protect the pavement; and if the covering is heavy enough, the pavement virtually becomes a foundation and is entirely protected from wear. On the other hand, the decay of a perishable material, as wood and asphalt, is hastened by a covering of street dirt which collects moisture and hastens the decay and disintegration of the pavement.

4. The presence of a street-car track on a street concentrates traffic at the two sides, thus virtually narrowing the street, and also causes the travel to go substantially in one track, a result which is particularly destructive of gravel and macadam roads.

5. The wider a pavement the more evenly will it wear, and consequently the longer it will last. If several irregular lines of travel can be maintained, the wear will be much more even and the durability greater than if the vehicles are restricted to practically a single line.

6. The durability of the pavement will vary with the weight per unit width of tire, the method of shoeing the horses, and the rapidity of the travel. In Europe, the weight per unit of width of tire is generally regulated by law, and calks on the horses' shoes are prohibited; but in America there are no such restrictions. Rapid travel is more destructive to a block pavement than slow travel.

7. The climate affects the durability of several kinds of pavement. The durability of an untreated wood pavement is affected by heat and moisture conditions, that of macadam and gravel by moisture and winds, and that of asphalt by moisture, particularly by street sprinkling.

1224. There are two facts of a somewhat different character that should not be overlooked in attempting to determine the life of a pavement.

1. The average wear does not determine the life of a pavement, since even the most carefully constructed pavements wear so unevenly as to require re-laying before the wearing coat is entirely worn out. This is true of sheet asphalt and gravel and macadam (both water-bound and bituminous), which have a comparatively thin wearing coat; and is particularly true of pavements made of blocks, as brick, stone and wood, since the edges of the blocks wear off and leave the top face rounded, and when the pavement reaches this stage the wear is much more rapid than previously.

2. In a block pavement the blocks must have a certain depth to enable them to keep their place; and consequently bricks and shallow wood blocks can not be worn more than about half-way through.

If the blocks are made deeper, the durability of the pavement is not increased much, if any, since owing to unequal wear the pavement must be re-laid before any considerable depth is worn off.

Asphalt and macadam have some decided economic advantages over other forms of pavements, since the wearing coat is comparatively thin and can be replaced when it is worn out or wears rough, without proportionally as much loss as when a block pavement is resurfaced. A further economic advantage of these pavements is that when holes begin to form, a patch may be applied and thus the uniformity of the surface may be preserved and the life of the pavement be extended.

1225. Data on Life of Pavements. Until more complete data concerning the volume of travel on pavements and the amount of wear are obtained, it will be impossible to make any reliable estimates as to the durability of different paving materials. At present the best that can be done is to accept the estimate of those most competent to give an intelligent opinion.

1226. *Asphalt, Brick, and Wood.* Table 79 gives the estimated life of sheet asphalt, brick, and wood-block pavements as reported to the U. S. Census Bureau. An extensive list was given for asphalt

TABLE 79

ESTIMATED LIFE OF PAVEMENTS*

Ref. No.	City.	Sheet Asphalt.		Brick.		Wood-block.	
		Business District.	Residence District.	Business District.	Residence District.	Business District.	Residence District.
1	New York City, N. Y.	12	15	11	11		
2	Boston, Mass.	10	15	5	10	15	20
3	Cleveland, O.	.....	14	.....	25	11	
4	Indianapolis, Ind.	10	12	10	25	.....	20
5	Portland, Ore.	5	10	.....	.....	9	
6	Columbus, Ohio.	11	14	18	18	13	
7	Toledo, Ohio.	10	20	10	25	.....	30
8	Atlanta, Ga.	11	14	12	25	17	18
9	Oakland, Calif.	15	25	.....	.....	15	
10	Cambridge, Mass.	12	.....	12	12	10	
11	Springfield, Mass.	12	.....	15	18	10	
12	Holyoke, Mass.	10	10	15	.....	8	
13	South Bend, Ind.	10	15	20	25	.....	15
14	Saginaw, Mich.	18	18	12	20	30	30
15	Sacramento, Calif.	12	20	.....	.....	25	
16	Galveston, Tex.	7	10	11	11	15	20

* General Statistics of Cities for 1909, Bureau of the Census, 1913, Washington, D. C., p. 69–70.

and brick, but only a brief list for wood-block; and only those in the former list are presented in Table 79, for which data were given also for wood-block.

Of course, the life of a pavement will depend upon the specifications and the details of the construction, which can not be presented in a tabular statement. Further, the life of a pavement depends upon the extent and character of the annual repairs. It is possible to keep some types of pavements, as for example sheet asphalt, going almost perpetually by patching; while with other forms, as for example brick, it is not possible to greatly prolong the life of the pavement by patching.

1227. *Granite.* The census report from which the data in Table 79 were taken, contained no statistics for the life of stone-block pavements. The following data to some degree supply that lack.

Mr. Samuel Whinery, a competent authority, estimates the life of granite-block pavements in Boston as follows: *

A, central business streets having a very large volume of the heaviest travel	13 years
B, secondary business streets with travel of moderate volume and weight	17 years
C, main city or suburban thoroughfares having a large volume of comparatively light travel	16 "
D, suburban or residence streets where the travel is mainly of a local character and light	20 "

Mr. George W. Tillson, Consulting Engineer, Borough of Brooklyn, estimates the life of a granite-block pavement at 25 years.†

The Bureau of Municipal Research of Cincinnati, Ohio, estimates the life of granite blocks at 25 years.†

1228. *Water-bound Macadam.* Macadam varies in quality more widely than any of the preceding forms of pavements, and hence there is a wider range in its estimated life.

Mr. Whinery estimates the life of trap-rock water-bound macadam for the four classes of streets mentioned in the second paragraph of § 1227, as follows:

A, 5 years; B, 6 years; C, 7 years; and D, 10 years.

The Bureau of Municipal Research of Cincinnati estimates the life of limestone water-bound macadam at 8 years.‡

* Report to the Finance Committee of Boston, Mass., *Engineering and Contracting*, Vol. 73 (1910), p. 30–31.

† Paper presented to International Municipal Congress, Chicago, *Engineering and Contracting*, Vol. 36 (1911), p. 405.

‡ *Municipal Engineering*, Vol. 42 (1912), p. 459.

1229. Requirements of an Ideal Pavement. The perfect pavement is an ideal which will never be attained, since some of the qualities required in a perfect pavement are antagonistic to each other. For instance, perfect durability would require a pavement without friction, for friction causes wear and ultimately destruction of the pavement; but without friction there could be no adequate foothold for horses drawing loads. Again, to be the least injurious to horses, a pavement should be soft and yielding; but a soft and yielding pavement is opposed to ease of traction. The conditions to be fulfilled by the ideal pavement will first be considered; and subsequently an attempt will be made to estimate the degree to which each kind of pavement approximates the perfect ideal.

A perfect pavement should satisfy the following conditions:

1. It should be low in first cost.
2. It should be durable, i. e., the cost of perpetually maintaining its surface in good condition should be small.
3. It should have a smooth, hard surface, so as to have a low tractive resistance.
4. It should afford a good foothold to enable horses to draw heavy loads, and to prevent them from slipping and falling and possibly injuring themselves and blocking traffic.
5. It should be smooth, so as to be easily cleaned.
6. It should be comparatively noiseless.
7. It should be impervious, so as to keep in good sanitary condition.
8. It should yield neither dust nor mud.
9. It should be comfortable to those who ride over it.
10. It should not absorb heat excessively.

Each of the ordinary forms of pavements will be considered under each of the above requirements.

1230. Cost of Construction. The cost of construction of a pavement varies with the specifications, the character of the work, and the locality. For detailed data on this subject, see the several kinds of pavements in the preceding chapters.

Since the subject under consideration in this chapter is a comparison of the different forms of wearing coats, the cost to be considered here is that of the pavement exclusive of the expense for curbs, gutters, catch-basins, etc. To have data for use in sample computations later in this chapter, the cost of the best grade of each of the several kinds of pavements is assumed to be as follows:

1. Asphalt, sheet..... $1.75 per sq. yd.
2. Brick..... 1.80 " " "

3. Granite block	3.00 per sq. yd.
4. Macadam, water-bound	1.25 " " "
5. Wood block, creosoted	2.75 " " "

1231. Cost of Maintenance. By the cost of maintenance is meant the expenditure necessary to keep the pavement in practically as good a condition as when it was new. Unfortunately there is a greater dearth of exact information under this head than for almost any other phase of pavement construction. For a general statement of the causes of this lack, see § 640–43 (page 321–26); and for a more detailed explanation why there is little accurate information on the cost of repairs of asphalt pavements, which reasons substantially apply also to all kinds of pavements, see § 881–82 (page 455–57).

The cost of maintenance consists of two distinct elements, viz.: (1) the cost of repairing or patching of small areas; and (2) the cost of renewing or re-surfacing large areas. Each will be considered separately.

1232. *Cost of Repairs.* The cost of repairs is here used as meaning the cost of correcting any defects that may have developed through use. Not infrequently this term is used to include also the expense of re-laying or restoring the surface of the pavement after it has been opened to lay or repair sewers, water or gas pipes, etc. In one sense the cost of restoring the surface after the pavement has been opened is part of the cost of maintenance; but the cost of restoring the surface is practically independent of the quality or life of the pavement, and hence should not be included in comparing the economic value of the different pavements.

Unfortunately, not many municipalities keep accurate accounts of the cost of repairing and restoring pavements, and very few separate the costs of patching and restoring; and hence there are almost no reliable data on the cost of repairs.

Further, many of the accounts purporting to show the cost of repairs contain one or both of the two serious errors discussed in the two succeeding sections.

1233. Repairs vs. New Construction. In computing the cost of repairs of roads and pavements, it is common to fail to discriminate between the renewal of an old surface and the substitution of a new and better surface; or, in other words, it is common to charge to maintenance an item which should be charged to new construction (see paragraph 6, § 881, page 455). For example, if some form of bituminous wearing coat is applied to an old water-bound macadam road, the new surface is not a renewal of the old one,

but is the construction of a new pavement surface upon the old one as a foundation; and consequently the cost of the new construction should not be regarded as the cost of repairs to the old pavement. This mistake in almost the exact form of the above example has often been made in discussions of highway economics. For example, it is often stated that the cost of road maintenance has recently taken an enormous leap upward due to the advent of the automobile; while the truth is that the advent of the automobile has caused the substitution of a more expensive form of road construction, and little or nothing is known as to the cost of maintenance of the new form of construction, partly because the methods of both construction and maintenance have been experimental, and partly because not enough time has elapsed to secure trustworthy data.

Because of the above error, many estimates of the cost of annual repairs are radically wrong, as also the resulting conclusions. Errors of this character have for somewhat obvious reasons been more common in connection with surfaces suitable for light travel than for heavy travel.

1234. AGE OF PAVEMENT. Sometimes an error is made by not duly considering the age of the pavement. During the first part of the life of a pavement, there should be but few, if any, repairs; and hence to secure a trustworthy value for the annual cost of repairs, an average should be taken for a number of years, the exact number being proportional to the life of each particular pavement.

Obviously, the greater the area of the pavements included and the greater the number of years the better; but it is not correct to simply take an average of the annual cost of repairs for each of several pavements of different ages and areas. Assume that the areas and ages of the several pavements are as below; that the total cost of repairs for each pavement is known; and that the correct average annual cost of repairs is desired.*

AREA, Sq. Yd.	AGE, Years.	YARDS × YEARS.
10 000	16	160 000
8 000	12	96 000
7 000	10	70 000
8 000	8	64 000
33 000		390 000

Multiplying the area by the corresponding age gives the number of yard-years that have been repaired, i. e., gives the equivalent of

* *Engineering and Contracting*, Vol. 37 (1912), p. 311.

the number of yards that have been maintained for 1 year. The total cost of repairs divided by the total yard-years (390,000) will give the correct average annual cost of repairs. The weighted average age of the pavement in the above example is: 390,000 ÷ 33,000 = 11.8 years.

1235. DATA ON COST OF REPAIRS. For a few data on the cost of the different kinds of pavements, see the preceding pages, as follows: Sheet asphalt, Table 47, page 457, and Fig. 162, page 459; brick, § 1069, page 564; wood block, § 1214, page 631.

Table 80 shows the best general data available, although it is not certain that these values, or the ones referred to in the paragraph above, are free from the two errors mentioned in the two preceding sections. Table 80 is given primarily to have data for use in sample computations to be presented later.

TABLE 80

ASSUMED AVERAGE ANNUAL COST OF REPAIRS

Kind of Pavement.	CENTS PER SQ. YD. PER ANNUM.	
	Heavy Travel.	Light Travel.
Asphalt, sheet,—see § 886	5.0	3.5
Brick,—see § 1069	3.0	2.0
Macadam, water-bound	10.0	2.0*
Stone block,—see § 1142	2.0	2.0
Wood block, creosoted,—see § 1214	4.0	2.0

1236. *Cost of Renewal.* The second element in the cost of maintenance of a pavement is the cost of renewal. Since the foundation or base of a modern pavement is not subjected to wear or disintegration, the cost of renewal is only the cost of adding a new wearing coat; although, not infrequently, the cost of a new concrete base is erroneously included in the cost of renewal (see § 1233).

The annual cost of renewal is that sum which each year must be placed at compound interest to accumulate a sum equal to the estimated cost of renewal at the end of the life of the wearing coat of the pavement. As an example, it will be assumed that the cost of renewal is desired for a sheet asphalt pavement. It will be assumed that the pavement costs $1.75 per square yard (§ 1230), and that the grading and concrete base cost $1.00 and the wearing coat $0.75. The latter is a little less than the pro rata share according to Table 45,

* Report Dept. of Public Works, Bureau of Engineering, Buffalo, N. Y., 1915–16, p. 70.

page 453; but round numbers are sufficient for an example. The life of the wearing coat will be taken as 15 years, which is probably too small, notwithstanding the data in Table 79, page 640. It will be assumed that the life of the concrete base is 30 years, which is probably too small; and that its removal will cost 20 cents per square yard. Interest will be assumed at $3\frac{1}{2}$ per cent. It will be further assumed that the removal of the old wearing coat will cost 10 cents per square yard. Finally, to find the annual sum to be placed at interest, a sinking fund table is desirable.

From a sinking-fund table it is found that \$0.05182 deposited annually at $3\frac{1}{2}$ per cent interest will amount to \$1.00 in 15 years; and that at the same interest \$0.01937 will amount to \$1.00 in 30 years. Then the annual cost of renewal is as follows:

Item.	Annual Cost Cts. per Sq. Yd.
Concrete base: renewal, \$0.75 × 0.01937	1.452
removal, 20 cents ÷ 30	0.667
Wearing coat: renewal, \$1.00 × 0.05182	5.182
removal, 10 cents ÷ 15	0.667
Total	7.968

In some cases there is a salvage value to the old wearing coat, in which case its value after removal divided by the life of the pavement should be subtracted from the annual cost found as above.

1237. *Economic Life of a Pavement.* When does the cost of repairs become great enough to justify renewal, that is, what is the economic life of a pavement? This subject has frequently been discussed by writers on road and pavement economics, and generally the method employed has been radically wrong. For an elaborate, correct, and instructive discussion of this subject, see Gillette's Hand-book of Cost Data, Second Edition, page 27–34.

1238. Tractive Resistance. Table 8, page 21, gives the tractive resistance of different pavements, from which it is seen that the rank of the various pavements according to tractive resistance, in order beginning with the one offering the least resistance, is about as follows: portland-concrete, sheet asphalt during cold weather, brick, best water-bound macadam, asphalt during warm weather, rectangular wood block, good gravel, accurately dressed stone block, ordinary water-bound macadam, gravel, roughly dressed stone block. The tractive resistance will vary greatly with the state of repair of the surface.

Many attempts have been made to compute the financial advan-

tage of a decreased tractive resistance; but it is impossible to determine its value with any degree of accuracy, although it is certain that the tractive resistance of the pavements of a city are important factors in determining the cost of conducting transportation. Ease of traction is, however, not relatively as important for city pavements as for country roads, since in the latter ease of traction is a matter of first importance (see § 4–7), while in the former it is comparatively unimportant (see § 634). On the other hand, the cost of transportation per ton-mile is considerably more in the cities than in the country.

1239. Slipperiness. The method of comparing pavements in this respect is to determine the distance a horse travels on the different pavements before he falls. The most complete observations made in the United States to ascertain the prevalence of accidents on the different pavements were made under the direction of Capt. F. V. Greene.* The observations were made from 7 a.m. to 7 p.m. on six consecutive days in October and November, 1885, in ten of the leading American cities on thirty-three streets having the heaviest travel for each kind of pavement in the particular city. The number of horses observed on sheet asphalt pavement were 360,254, on old-style granite block 376,384, and on wood 70,914; and the number of miles traveled by the horses while under observation was 41,427 on the asphalt pavements, 34,723 on the granite, and 4,901 on the wood. A summary of the results is shown in Table 81.

TABLE 81

MILES TRAVELED BY A HORSE ON AMERICAN PAVEMENTS BEFORE AN ACCIDENT OCCURS

Observations made in 1885

Ref. No.	Kind of Pavement.	Fall on Knees.	Fall on Haunches.	Complete Fall.	Accident of Any Kind.
1	Asphalt, sheet	1 534	2 180	1 647	583
2	Granite block—old style	510	5 954	3 472	413
3	Wood[1]	408	983	4 901	272

[1] The kind of wood-block is not stated, and apparently it can not now be determined.

These data are very much out of date, and are not of much value, since the character of the prevailing forms of construction has materially changed; but nevertheless Table 81 contains the only

* Trans. Amer. Soc. of Civil Engineers, Vol. 15 (1886), p. 123–28.

definite data on record for American pavements. No observations similar to the preceding have been made for brick pavements; but it is probable that they are less slippery than asphalt, wood-block, or stone-block. It is certain that modern stone-block pavements, i. e., those with comparatively small blocks and narrow joints filled with bituminous or hydraulic cement, are less slippery than the old-style stone-block pavement upon which the observation in Table 81 were made.

1240. The above observations relate to the slipperiness for a horse; but slipperiness is nearly as important for an automobile as for a horse. However, no systematic observations have been made as to the effect of slipperiness of pavements upon automobile traffic.

1241. *Conclusion.* It is generally conceded that wood-block pavements are the most slippery, sheet asphalt next, brick next, and then granite.

1242. *Investigation in Progress.* In 1916 the State Highway Commission of Massachusetts built ten sections of pavements primarily to determine their relative slipperiness. Incidentally it is expected that the experiment will demonstrate other things of interest.*

The test sections were built on Washington Street, Boston, on a 4 per cent grade, and each is 500 feet long. The surfaces of the several sections are those ordinarily employed for rural and suburban roads rather than those used on city streets; and consist of two of tar macadam (§ 604), two of asphalt macadam (§ 604), two of tar concrete (§ 604), one of asphalt concrete (§ 604, 891, and 901), one of hydraulic concrete (Chap. VII), one of tar and sand (§ 614), and one of Topeka asphalt mixture (§ 897–98). Each of the first three forms of pavements was laid with a " rough " and a " smooth " surface.

The different materials are subject to the same conditions, and hence are strictly comparable; and the same materials were used in the several sections, and hence the methods of construction are strictly comparable. The only noteworthy conclusions that have been announced relate to the durability of the several forms of construction; and no decision has been reached as to the relative slipperiness of the different surfaces.

1243. Ease of Cleaning. The facility with which a pavement may be cleaned is an important matter both economically and

* *Engineering News*, Vol. 76 (1916), p. 1162.

esthetically. Col. Geo. E. Waring, noted for his service as Street Cleaning Commissioner of New York City, in 1896 estimated that if all the streets of New York City were paved with asphalt where the grades would permit, the cost of street cleaning would be reduced from $1,200,000 to $700,000 per year. At that time New York had 431 miles of pavement of which 94 were asphalt, and the above annual saving is equal to 3 per cent of the cost of laying asphalt pavements upon all of the streets not already asphalted.

Sheet asphalt and hydraulic concrete pavements are most easily cleaned, and next in order are: wood blocks with close joints, asphalt blocks, brick with joints filled with hydraulic cement, accurately-dressed stone blocks with cement joints, and old-style stone blocks.

Macadam and gravel are smooth and for this reason are easily cleaned; but their surfaces, particularly if water-bound, grind up into powder under dense or heavy travel, and for this reason there is considerable detritus to be removed, a fact which adds to the expense of cleaning.

1244. Noiselessness. The noise made by travel upon a pavement has an important effect upon the comfort and health of the people using the pavement or living adjacent to it. A quiet pavement is particularly desirable adjacent to office buildings, schools, churches, hospitals, etc.; and the noise of travel upon a rough pavement aggravates, if it does not cause nervous disorders.

On sheet asphalt and hydraulic concrete, and well-grouted brick, the only noise is the sharp click of the horses' shoes; and on asphalt block and re-pressed brick filled with tar or grout, there is the click of horse's shoes and a slight rumbling of the wheels passing over the joints. On well-dressed granite blocks filled with hydraulic cement, there is a considerable rumbling due to the passage of heavy steel-tired vehicles; and on the old-style granite block with sand-filled joints, there is a deafening roar due both to the rumbling of the wheels and to the blows of the horses' shoes. Upon wood pavements the horses' feet produce no noticeable noise; while the wheels make a dull rumbling noise, but not loud enough to be seriously objectionable. Macadam and gravel are more quiet than wood.

In order of their freedom from noise, pavements rank about as follows: wood-block having the joints filled with tar or grout, sheet asphalt, asphalt block, asphalt concrete, hydraulic concrete, square-edged brick having grouted joints, re-pressed brick having joints filled with tar or grout, accurately dressed stone blocks having joints filled with grout, and old-style stone block. Bituminous gravel

and macadam are nearly as quiet as sheet asphalt, and water-bound gravel and macadam are not seriously noisy. However, the freedom from noise on any pavement depends greatly upon the care used in construction and maintenance.

1245. Healthfulness. The effect of a pavement upon the health of the residents in its locality will depend upon the tendency of the materials composing it to decay, and also upon its permeability. The healthfulness of a pavement was much more important formerly than at present. The form of pavements that were most unhealthful have gone out of use. These are: cobble-stone and stone-block pavements having joints filled with pebbles, cylindrical wood-blocks with sand-filled joints, and stone-block having wide joints filled with sand or pebbles. The difference in healthfulness of the best modern pavements is negligible.

1246. Freedom from Dust and Mud. The materials of an ideal pavement should not grind up and make dust in dry weather or mud in wet weather. The dust and mud not only add to the expense of cleaning the pavement, but are a discomfort to those who use the pavement and to those who live or do business adjacent to it.

1247. Comfort in Use. If the pavement is to be used for pleasure driving, the comfort of the users must be considered; and therefore the pavement should have a smooth surface which is free from dust when it is dry and free from mud when it is wet.

1248. Temperature of Pavements. During hot weather, there is frequently complaint that one pavement reflects or radiates more heat than another. Observations made in Washington, D. C., when the temperature of the air 2 feet above the pavement was 104° F., showed the temperature of three pavements to be as follows: sheet asphalt 140°, asphalt block 122°, and macadam 118°.* Observations in Boston, when the temperature of the air in the shade was 98° F., gave the temperature of four pavements as follows: wood block 124½°, granite block 115°, sheet asphalt 113°, and macadam 102½°. The observations are not conclusive as to the relative temperatures of different pavements, but show that there is no very great difference between the several kinds. The temperature of the pavement depends upon its color, which varies with the material.

* Proc. Amer. Soc. Municipal Improvements, Vol. 5, p. 161.

Art. 2. The Solution of the Problem

1250. The problem of selecting the best pavement for any particular case is a local one, not only for each city but also for each of the various parts into which the city is imperceptibly divided; and involves so many elements that the nicest balancing of the relative values for each kind of pavement is required to arrive at a correct conclusion.

There are two methods that may be employed in deciding which is the best of several pavements. One method assumes that the selection should be made upon economic grounds alone, in which case the best pavement is that for which the total annual expense is a minimum. The other method assumes that the decision should be based upon other factors beside the economic features. Each of these two methods will be considered; and for convenience the first will be called a Problem in Economics, and the second a Non-economic Problem.

1251. Problem in Economics. As a problem in economics, the selection of the best pavement consists in finding that form of pavement, or wearing course, for which the total annual cost is least. The annual cost consists of (1) interest on the cost of construction, (2) the annual cost of repairs, (3) the annual cost of renewal, (4) the annual cost of cleaning, (5) the annual cost of conducting the transportation the pavement carries, and (6) the annual cost of sprinkling,—when that is necessary.

The first three items of cost have already been considered in Art. 1. The last three items of expense have not been considered; but will now be briefly discussed.

1252. Cost of Cleaning. Some forms of pavements require sprinkling for economic maintenance, as for example water-bound macadam; and some types require sprinkling for the comfort of the users and of those living adjacent to it.

The cost of cleaning depends upon the amount and character of the travel and also upon the smoothness of the pavement, and more upon the former than the latter. The difference in cost of cleaning the different forms of modern pavements is not great. For example, in 1895–97 in New York City it was determined that the relative ease of cleaning different pavements was as follows: asphalt, brick and rectangular wood-block, each 100; granite block, 150; Belgian block, 160; and cobble-stone, 400. But since the date of that inves-

tigation, cobble-stone pavements have been practically eliminated, and Belgian blocks nearly so; while the prevailing type of construction of granite-block pavements has changed so that now they are practically as smooth as brick pavements. Hence, if the cost of cleaning is omitted, it will not materially affect the conclusion as to the relative economic merits of the different pavements.

1253. Cost of Transportation. At first thought, it does not appear that the cost of conducting the transportation over a pavement is part of its annual cost; but really the cost of the transportation is a part of the cost of operating the pavement, and hence is a part of its annual cost. The cost of construction is usually paid by the abutting property holder, and ordinarily he pays also the cost of repairs and renewals; the city usually pays the cost of cleaning; and the owners of the horses and wagons and of the motor cars pay the cost of transportation.

Modern pavements are so nearly alike in the smoothness and hardness of their surfaces that there is no material difference in the cost of conducting transportation on them. Further, the transportation is conducted by so many different parties under so many different conditions, that it is practically impossible to determine its cost with any degree of accuracy.

Therefore, for lack of the requisite data, it is necessary to omit the cost of transportation from the summary of the annual cost of the pavement; but this omission does not materially affect the conclusion as to the most economical pavement.

1254. Cost of Sprinkling. Water-bound macadam is about the only pavement that requires sprinkling, either for maintenance or for the comfort of users of the pavement or of those living adjacent to it. The cost of sprinkling will vary widely with the local conditions—the character and amount of the travel, the climate, the material of the road surface, the quality of the construction, etc.

Since this form of pavement surface is rapidly going out of use, there are no recent data on this subject. Further, such pavements are not likely to be constructed to any appreciable extent in the future. Therefore, this item will be disregarded.

1255. Total Annual Cost. The cost of construction is stated in § 1230 (page 642); Table 80 (page 645) shows the cost of repairs; and § 1236 (page 645) shows the method of computing the cost of renewals.

The method of computing the total annual cost of a sheet asphalt pavement under heavy travel is as follows:

Items.	Annual Cost Cts. per Sq. Yd.
Interest: concrete base, \$1.00 at 3½ per cent	3.500
wearing coat, \$0.75 at 3½ per cent	2.625
Repairs (Table 80, page 645)	5.000
Renewals (see § 1236, page 645)	7.968
Total interest, repairs, and depreciation	19.093

1256. *A Common Error.* Not infrequently, in computing the annual cost of a pavement, there is added to the above items an annual contribution to a sinking fund sufficient to redeem the bonds issued to pay for the pavement. This is incorrect, since a bond issue is only a means of deferring the payment of the first cost; and it is clearly wrong to include both interest on first cost and an annuity to pay the first cost. If the bond matures at the end of the life of the pavement, an annuity to redeem the bond is precisely the same thing as a depreciation fund to renew the pavement; and hence it is clearly an error to include both in the annual cost.

1257. *Comparison of Total Annual Costs.* To compare the economic value of different pavements, a computation similar to that in § 1255 should be made for each pavement; and the one showing the least annual cost is the most economical. Substantially the above method was applied to three forms of pavements and four classes of streets in a certain large city, with results in Table 82.*

TABLE 82

Annual Cost of Pavements

Kind of Pavement.	Classes of Streets.			
	A.	B.	C.	D.
Granite block	\$0.511	\$0.372	\$0.365	\$0.294
Sheet asphalt	.521	.324	.283	.222
Water-bound macadam	.669	.430	.312	.151

Although the error mentioned in § 1233, i. e., not discriminating between renewal and new construction, was made in computing the cost of repairs of the macadam, the results are sufficiently correct to show the method of utilizing such an investigation. The computations included a charge for cleaning for each form of pavement, and

* *Engineering and Contracting*, Vol. 33 (1910), p. 31.

also an item for sprinkling the macadam. Of the four classes of streets, A had the heaviest travel and D the least. The results show that for Class A streets, a granite block pavement is most economical; for Class B, sheet asphalt; for Class C, sheet asphalt; and for Class D, macadam.

Of course, the value of an investigation similar to that above depends upon the values assumed for the life of each of the pavements, and also upon the value used for the cost of repairs; but unfortunately there are practically no reliable data for either of these, and hence this method is not as exact as its form implies. For example, for any of the four classes of streets in Table 82, the differences in the annual costs of the three pavements are so small that the conclusions might be changed by a change in the assumed life of one or the other of the pavements.

1258. Non-Economic Problem. Sometimes the selection of a pavement is determined by a single factor, as for example, the proximity of one or more paving materials, and sometimes the selection can be made from a consideration of only the economic features (see § 1251–58); but usually the selection requires a careful consideration of all the factors involved. The benefits to be derived from good pavements are stated in § 634 (page 318–19), from which it appears that only two of the eight advantages relate directly to economics. The requirements for an ideal pavement are enumerated in § 1229, from which it appears that only five of the ten items concern economics.

The decision as to which is the best pavement will often be largely a matter of judgment; and when this is the case, the engineer should reach his conclusion by a series of carefully considered steps, and not by a single haphazard leap. He should weigh all the evidence, and not base a decision upon a single item, as is too often the case; nor should he adopt the practice of some other locality without a careful consideration of the local resources and of the needs of the place in which the pavement is to be laid, as is frequently done.

Local conditions should always be considered, and hence it is not possible to lay down any fixed rule as to what material makes the best pavement; but a careful study of the requirements of the ideal pavement and of the qualities of the different kinds of pavements will promote an intelligent selection in any particular case.

1259. Relative Merits of Pavements. It is proposed to compare different kinds of pavements by assigning percentages to the different qualities of an ideal pavement, and then with this as a guide to assign

numerical values to the various qualities of the several kinds of pavements.

The various qualities of a perfect pavement have been discussed in § 1229 to § 1248, and these qualities have been grouped in Table 83 under the three heads: (1) economic qualities, (2) sanitary qualities, and (3) acceptability. Opposite each of these qualities in the first column of Table 83 is placed a number which is believed to represent the average relative importance of that particular quality on a scale of 100.

TABLE 83

RELATIVE VALUES FOR THE DIFFERENT QUALITIES OF VARIOUS PAVEMENTS

Ref. No.	Qualities.	PERCENTAGE ASSIGNED TO THE QUALITY.					
		Ideal Pavement.	Sheet Asphalt.	Brick.	Granite Block.	Water-bound Macadam.	Wood Block.
	Economic qualities:						
1	Low first cost	20	11	10	3	18	5
2	Low cost of repairs	20	14	18	20	8	16
5	Ease of traction	10	9	8	7	6	9
4	Good foothold	5	2	4	4	5	2
5	Ease of cleaning	10	10	9	6	3	9
	Total	65	46	49	40	40	41
	Sanitary qualities:						
6	Noiselessness	15	10	7	5	15	14
7	Healthfulness	5	5	4	3	2	4
	Total	20	15	11	8	17	18
	Acceptability:						
8	Free from dust and mud	10	10	9	8	2	9
9	Comfortable to use	3	3	1	1	3	2
10	Non-absorbent of heat	2	1	1	1	2	1
	Total	15	14	11	10	7	12
	Grand total	100	75	71	58	64	71

The most important matter in preparing Table 83 is the assignment of the numbers for the Ideal Pavement, for the number assigned to any one quality limits the range of the corresponding assignments to the different pavements. The assignment of the numbers is wholly a matter of judgment, and different individuals will differ greatly as to the relative values to be given to each quality; but the table is only to show a method whereby the good and the bad qualities

of one kind of pavement may be balanced against those of another kind, and a conclusion may be reached, step by step, which represents the algebraic sum of the judgment on each item.

Different values should be assigned to the same quality according to the attendant conditions. If the street is in a manufacturing district and subject to heavy traffic, ease of traction should be assigned a comparatively high value, and noise a very low value. For an office district, quietness is the controlling factor, and should therefore have a relatively high value. Similarly, for a residence district with its light driving, healthfulness and freedom from dirt and dust may be the most important element; for a residence district where the property owners can not afford an expensive pavement, the first cost may determine the kind of pavement; and on a steep grade slipperiness may out-weigh all other conditions in determining the kind of pavement to be employed. The application of the principles is likely to be complicated by the personal interests of the residents or property-holders, since opinions are likely to differ according to whether the point of view is that of a tenant, a resident property-holder, or a non-resident property-holder.

1260. Each quality of a pavement will now be considered, and the degree of perfection of this quality possessed by each kind of pavement will be indicated by a numerical value.

1261. First Cost. In § 1230 (page 642) are given assumed values for the average cost of construction for the best of each kind of pavement. These values are repeated below in the order of their cheapness:

Kind of Pavement.	Cost per Sq. Yd.	Relative Weight
1. Macadam, water-bound	$1.25	18
2. Asphalt, sheet	1.75	11
3. Brick	1.80	10
4. Wood block, creosoted	2.75	5
5. Granite block	3.00	3

The last column of the above exhibit shows the relative weights assigned to the quality of cheapness. Since macadam is the lowest in first cost, it possesses the quality of cheapness in the highest degree; and consequently it is given a weight of 18—nearly the value assigned to the ideal pavement in Table 83. The weights assigned to this quality decrease from gravel, the cheapest, to granite block, the most expensive. The several weights assigned above to low first cost are entered opposite this quality in the table.

1262. The first cost of a pavement not infrequently has undue weight in comparing the relative merits of different kinds of pave-

ments. The pavement which costs the most to construct is not always the most expensive, nor is the one lowest in the first cost always the cheapest in the end (see § 1251–57).

A pavement is sometimes selected because of its low first cost, for other than economic reasons. Often the cost of construction is charged against the abutting property, while maintenance is paid for by the whole city; and the result is that many property owners perfer a cheap pavement because they must pay for it, notwithstanding the fact that the cheaper pavement may cost more for maintenance and be dearer in the long run. Again, the property holders are sometimes really unable to pay for the most economical pavement, and hence a pavement low in first cost is selected as a temporary expedient.

1263. Cost of Repairs. Table 80, page 645, contains the best available data on the cost of repairs, although they are not very reliable. The data for heavy travel are re-arranged and transcribed below:

Kind of Pavement.	Cost per Sq. Yd.	Relative Weight.
1. Stone block	2.0	20
2. Brick	3.0	18
3. Wood block	4.0	16
4. Asphalt	5.0	14
5. Macadam, water-bound	10.0	8

1264. Ease of Traction. Under this head may be included not only the power required to move loads, but also the consequential damages to vehicles, since they both vary with the roughness of the pavement. From a study of the results in Table 8, page 21, remembering that the tractive resistance of the best type of several of the pavements has decreased since the observation in Table 8 were made, the weights are assigned to this quality for the different kinds of pavements, as shown in Table 83.

1265. Foothold. From a study of § 1239, the relative degree of slipperiness is stated in numbers and entered in Table 83. If the pavement is to be upon a steep grade, this quality may be a controlling factor.

1266. Ease of Cleaning. The relative ease with which certain types of pavements may be swept, as determined by the cost of doing the work in New York City, is as follows: asphalt, 100; brick, 100; rectangular hard-wood blocks, 100; granite blocks, 150; Belgian blocks, 160; cobble stones, 400.* For sanitary reasons, New York

* Street Cleaning in New York City in 1895–97, p. 157—Supplement to Vol. II. of Municipal Affairs. New York, 1898.

City has spent a million dollars a year for the past few years in substituting sheet asphalt pavements for stone-block in the congested tenement districts, chiefly on account of the greater ease with which the asphalt is kept clean.

The cost of sweeping ordinary stone-block, round wood-block, and brick with sand filler usually ranges between 40 and 48 cents per 1,000 square yards for each sweeping, and sheet asphalt from 30 to 38 cents, depending upon the thoroughness of doing the work, the frequency of sweepings, the kind of business in the property adjoining, and the amount of the traffic. The relative weight to be assigned to this item will vary with the frequency of cleaning.

The estimated weight to be assigned to the several pavements on account of their ease of cleaning is entered in Table 83.

1267. Value for Other Qualities. From a consideration of the discussion in § 1244–48, the percentages for the other qualities are inserted in Table 80.

1268. Conclusion. The totals at the foot of Table 83 represent the summation of the individual decisions on the several qualities, and the larger the total the more desirable the pavement. The particular results in this example may not be applicable to any locality, and each person will have his own opinion as to the merits and defects of any particular pavement; but the method of analysis is applicable to any particular case, and will enable the engineer intelligently and unerringly to reach the final conclusion to which his opinion in detail leads. The above method has something of the mathematical form; but the fact should not be forgotten that it is based upon judgment, and that therefore it can not be expected to give results of a high degree of accuracy.

In practice the application of this method is much less complicated than appears from the above example, for usually proximity of some natural pavement material or freight rates on others, limits the choice to a comparatively few kinds of pavements. Further, the decision as to the kind of pavement to be laid is often influenced by the fancy or ability of those who pay for it. However, the engineer should employ a logical process in arriving at his own conclusions, and thus be in a position to give sound advice upon the fundamental principles involved.

1269. Finally, in any important case, it is wise to determine the best pavement by both the economic and the non-ecomonic method, so as to check one method against the other.

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